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Cedar River Municipal Watershed
Upland Forest Restoration Strategic Plan

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EXECUTIVE SUMMARY

Upland forest restoration to actively accelerate the development of late successional forest conditions and increase habitat complexity in second-growth forest is a key component of the Cedar River Watershed Habitat Conservation Plan (CRW-HCP). Implemented in April of 2000, the CRW-HCP effectively placed nearly 85,500 acres of forests in the Cedar River Municipal Watershed (CRMW) in reserve status by prohibiting the harvest of timber for commercial purposes and mandating management to accelerate the development of late successional forest conditions through silvicultural intervention. This effort is aimed at facilitating and restoring natural forest processes while increasing the habitat available for late-successional forest dependent species (e.g., northern spotted owl, marbled murrelet) and improving the overall water quality in the CRMW by restoring a water cycle more typical of pre-development forest conditions. Second-growth forest, occupying land harvested prior to the adoption of the CRW-HCP, currently make up 71,500 acres of the CRMW, while the remaining 14,000 acres are late-successional or old-growth forest. This plan outlines how forest restoration will be implemented in the CRMW to accelerate the development of late successional forest conditions and increase habitat complexity in second-growth forests.

Over the term of the HCP, the upland forest restoration program will use a combination of carefully planned intervention in previously logged forest and leave areas to develop without intervention. The intent is to produce the largest percentage of ecological function over the watershed landscape over time for species of concern and to restore biodiversity by designing and implementing interventions prescribed in the HCP in the optimal spatial pattern and temporal sequence. The restoration program is designed to use intervention in the most cost-effective manner to achieve the overall goals.

The upland forest restoration program is being planned concurrently and integrated with other kinds of restoration activities across the landscape to produce the greatest overall benefit for species of concern. Upland forest restoration is planned on a landscape level by considering key ecological processes and patterns of distribution at the landscape scale, both within and beyond the municipal watershed. On a broad temporal scale, upland forest restoration is being planned to try to develop a forest ecosystem that is resilient with respect to potential changes in climate, conditions surrounding the municipal watershed, and species. A key approach to creating this resiliency is to develop diversity within the forest ecosystem.

Protection will occur where forests are already developing desired characteristics and/or have high levels of biological diversity. In other areas, restoration of second-growth forest will seek to limit the time forest areas spend in the competitive exclusion stage of forest succession, thereby reducing the time to develop large trees, snags, downed wood, and the complex structure and biodiversity typical of late successional and old growth forests. This restoration will take place in the form of *upland ecological thinning* in selected forest areas generally between 30 and 60 years old, *upland restoration thinning* in selected forest areas between 15 and 40 years old, and *upland restoration planting* in areas where biodiversity is lacking.

The current annual targets for each restoration project type are at least 62 acres for ecological thinning for the first 16 years and then 25 acres for the remainder of the CRW-HCP; 700 acres for restoration thinning through the first 15 years of the CRW-HCP; and upland restoration planting in areas that have low biodiversity and, in the near-term, in conjunction with ecological thinning. Planting is planned to include non-traditional approaches, such as "inoculating" areas of forest with lichens and mosses. Combining these restoration project types, the HCP calls for the treatment of a total of 13,480 acres, or about 19 percent of the existing second-growth forest, based on costs per acre as originally estimated. This total is based on the assumption that planting will be done on areas that are not thinned, which will often not be the case. Ecological thinning would occur in only about 3 percent of the existing second-growth forest at the rate described in the HCP. Second-growth forest from 40 to 60 years old offers the greatest opportunity for developing late-successional forest habitat conditions in the near to middle term. Given that there are nearly 50,000 acres of second-growth forest in this age range, it is questionable whether the level of intervention using ecological thinning and restoration planting prescribed in the HCP can have a significant landscape level effect on listed species with medium or larger home ranges. SPU is developing data to assess forest conditions and is evaluating options for potentially higher levels of thinning and planting to produce greater ecological benefits per dollar spent.

Though the overall goal of accelerating the development of late successional forest conditions while enhancing water quality and quantity applies to each of the three forest restoration project types, specific objectives differ. Ecological thinning objectives include maintaining or increasing tree growth, encouraging tree crown development, increasing species diversity, increasing structural and spatial complexity, accelerating understory development, and improving late successional and old-growth forest habitat connectivity. Restoration thinning objectives include reducing competition among trees, increasing light penetration to the forest floor, stimulating tree growth, reducing long-term fire hazard and other catastrophic loss, and accelerating forest development through the competitive exclusion stage of forest succession. The objectives of upland planting are to increase species diversity of trees, shrubs, or other flora in areas of relatively low biodiversity.

Forest characteristics and the juxtaposition of habitat types on the landscape will be used to identify and prioritize restoration project locations. There are many site selection and prioritization criteria identified for ecological thinning, restoration thinning, and upland restoration planting projects. The Watershed Management Division (WMD) currently has several datasets and tools that can be used to identify forests with appropriate characteristics for restoration, and the development of additional data will be an ongoing process as forests grow and change over time. Potential near-term project locations are systematically identified and the process is established for locating projects in the longer term, as new data becomes available.

There are many forest restoration efforts taking place throughout the Pacific Northwest, although no one has yet developed late-successional forest through active forest management. To address this uncertainty, the forest restoration program in the CRMW will monitor these other efforts, as well as the success of its own projects, to ensure that the interventions utilize the current state of knowledge. The standards and guidelines for implementing individual forest restoration projects are also identified in this plan, which is intended to guide the forest restoration program in the CRMW and provide program transparency to the larger community.

1.0 INTRODUCTION

Upland forest restoration, or actively accelerating the development of late successional forest conditions in degraded second-growth forest, is a key component of the Cedar River Watershed Habitat Conservation Plan (CRW-HCP), developed under Section 10 of the federal Endangered Species Act. The CRW-HCP includes a variety of conservation measures, including the active restoration of upland second-growth forest, required to meet the terms of an Incidental Take Permit for listed species among the 83 wildlife species covered by the plan. These species include 21 birds, 19 mammals, 14 amphibians and reptiles, 10 fish, 14 insects, and 5 mollusks. Old-growth forest is a key habitat for 28 of these species (including the northern spotted owl [*Strix occidentalis caurina*], marbled murrelet [*Brachyramphus marmoratus*], and northern goshawk [*Accipiter gentilis*]), while the restoration of second-growth forest to late successional forest habitat will benefit most of the other species tangentially by restoring the Cedar River Municipal Watershed (CRMW) to a more natural landscape condition.

Of the 90,546 acres encompassed by the CRW-HCP, 85,477 acres are forested, with 13,980 acres currently in late-successional or old-growth forest conditions[1]. The remaining 71,497 acres are second-growth forest. These younger forests are available for recruitment into late-successional forest habitat and are potentially available for restoration intervention. As stated in the CRW-HCP:

> *The general objective of the late-successional and old-growth communities component of the watershed management mitigation and conservation strategies is to develop significantly more mature and late-successional forest habitat in the watershed that will support species addressed in this HCP that are dependent on late-successional or old-growth forests, as well as old-growth biological communities in general.* (CRW-HCP 4.2-33).

The importance of natural processes and biological diversity is recognized in the CRW-HCP, and a major objective is to:

> *…develop strategies to restore and sustain the natural processes that create and maintain key habitats for species addressed by the HCP and that foster natural biological diversity of native species and their communities.* (CRW-HCP 4.2-10).

To help achieve these objectives, the upland forest restoration program will use interventions designed to accelerate development of late-successional forest characteristics and enhance natural forest processes. Techniques will attempt to mimic, to the extent possible or known, the process of forest development and the actions of natural disturbances that result in the complex habitat structure and biological diversity found in unmanaged late-successional forests in the maritime Pacific Northwest.

[1] Old-growth forest is a subset of late-successional forest, with old-growth forest being loosely defined in the CRW-HCP as forest greater than 190 years of age, and late-successional forest being defined here as those in the understory reinitiation and old-growth stages of forest succession (see Section 3.1.1).

1.1 Purpose of This Document

The purpose of this document is to:

- define the goals and objectives of the upland forest restoration program;
- provide an overview of forest restoration, including the current state of the science, the rationale, and resulting strategy for implementing forest restoration in the CRMW;
- develop criteria for project site selection and prioritization among project sites that will ensure the greatest ecological benefit at the lowest cost;
- review available data, define information needs required to obtain restoration goals, and identify the data and tools required to both identify areas in need of restoration and prioritize among them (on a basin and watershed scale);
- develop a monitoring and adaptive management program for upland forest restoration that will address the most significant scientific uncertainties about natural processes and the effects of restoration activities being undertaken in the CRMW;
- delineate standards and guidelines for the project planning, design, and implementation process; and,
- identify the ongoing role of the Upland Forest Restoration ID Team (UFRIDT), which is made up of members of the Ecosystems Section, Watershed Management Division (WMD), Seattle Public Utilities (SPU).

1.2 Strategic Asset Management Framework

Asset management is a priority in SPU's overall management strategy, and is defined by SPU as "the meeting of agreed customer and environmental service levels at the lowest life cycle costs." This plan sets the stage for implementing the Upland Forest Restoration Program within the strategic asset management context, by identifying service levels (e.g., restoration treatment goals), outlining the life cycle costs and benefits of accelerating the development of late successional forest conditions, providing a context for benchmarking with similar forest restoration programs, and outlining a monitoring plan to validate that project objectives are being reached and for instituting adaptive management.

In the asset management context, service levels as anticipated and directed by the CRW-HCP are clearly stated in Section 2.0 of this strategic plan (The CRW-HCP Upland Forest Restoration Program). The risks and uncertainties in achieving those service levels, including key questions that must be addressed in order to assess those risks and uncertainties, and the current status of other relevant forest restoration programs, are outlined in Section 3.0 (Theoretical Framework for Upland Forest Restoration). Knowledge regarding the forest assets of the CRMW is presented in Section 4.0 (Forest Habitat in the CRMW), while the strategy to systematically implement the forest restoration program within a prioritization framework is addressed in Section 5.0 (Framework for Project Site Selection and Prioritization). The action plan for using and developing forest data to guide project site selection and prioritization is included as Section 6.0 (Data and Analytical Tools). Based on the prioritization framework and available data, near-term forest restoration project sites are identified in Section 7.0 (Near-Term Forest Restoration Project Sites). A strategy for supplementing and maintaining information about the program and how it compares to other similar programs is described in Section 8.0 (Benchmarking, Monitoring, and Adaptive Management). And finally, an action plan for implementing individual projects within the program is presented in Section 9.0 (Standards and Guidelines for Project Planning and Implementation), and the ongoing role of the UFRIDT is defined in Section 10.0 (Oversight Role of the Upland Forest Restoration ID Team).

2.0 THE CRW-HCP UPLAND FOREST RESTORATION PROGRAM

2.1 Primary Program Goals and Objectives

The CRW-HCP establishes the CRMW as an ecological reserve where the harvest of timber for commercial reasons is expressly prohibited and includes a number of active restoration measures required under the related Incidental Take Permit. The CRW-HCP identifies and makes explicit commitments regarding three forest restoration activities (upland ecological thinning, upland restoration thinning, upland restoration planting [see Section 2.3]) that are designed to achieve the broad goals of accelerating late-successional forest conditions and restoring and sustaining natural processes while protecting and/or enhancing water quality and quantity. Recognizing that forest structural conditions and processes will continue to evolve with or without intervention throughout the 50-year CRW-HCP implementation period, restoration interventions are intended to accelerate those processes that lead to desirable habitat conditions, restore ecological processes to a more natural state, and increase biological diversity associated with late-successional forests. Each of the three upland forest restoration activities focuses on affecting different processes and conditions in watershed forests and uses different techniques.

2.2 Additional CRW-HCP Goals and Commitments

Several additional goals are addressed in this document and through the planning and implementation of upland forest restoration projects.

2.2.1 Use of the Best Available Science in Upland Forest Restoration

The science of forest restoration is a relatively young discipline, with targeted work only beginning within the past several decades. Forest succession in forests west of the crest of the Cascade Mountains in the Pacific Northwest proceeds slowly, over centuries. Consequently, the time needed to judge the success of forest restoration typically is decades or centuries. Not surprisingly, no one has yet restored a functioning late-successional or old-growth forest through active restoration management. Since the primary efforts to date to restore second-growth forests to late-successional conditions have been limited and have been made in the context of experiments begun within the last two decades (see Section 3.3), we must consider many of the proposed restoration activities in the CRMW as experimental. In addition, much is unknown about the natural processes of forest succession, especially in later stages of development and in true fir forest types (Curtis et al. 2000, Franklin et al. 2002). Given this uncertainty, the CRW-HCP commits to using the most recent data and scientific understanding available (obtained through literature searches and consultation with experts – see Sections 3.3 and 8.1), and an approach of monitoring and adaptive management (see Section 8.2). This approach will facilitate learning about natural processes by the comparison of treated areas with untreated areas, and by modifying intervention methods over time as we gain knowledge in an adaptive management framework.

2.2.2 Coordination with Other CRMW Planning Efforts

Planning upland forest restoration projects requires close collaboration and coordination with other WMD restoration planning efforts, including leaders of WMD work units, other interdisciplinary (ID) teams, and WMD Operations and Ecosystem staff. Project coordination has several potential advantages, including an opportunity to combine restoration techniques for greater ecological benefits in a cost effective manner, combine riparian, aquatic, and upland treatments for greater landscape-level effects, combine data collection for planning and monitoring purposes, and limit disturbance to wildlife by concentrating disturbance from various projects into a short time frame. Upland forest restoration projects will be coordinated within sub-basins with riparian and aquatic restoration projects. It is also essential that restoration projects be coordinated with road decommissioning plans to ensure adequate access for project implementation and long-term monitoring.

Though restoration project site selection to date has been made using the best available data and informed professional opinion by WMD staff (see Section 7), the UFRIDT is using data in development by the Watershed Characterization ID Team (WCIDT). The UFRIDT and other planning staff will use data developed by the WCIDT or from other sources to guide long-term project site selection and prioritization. The WCIDT is also providing data dictionaries, standards for data collection, and meta-data methodology, which will be used to standardize, document, and access the data. Both CRMW-wide and project-specific monitoring plans for upland forests will be prepared consistent with the Strategic Monitoring Plan now being developed by the Monitoring ID Team (MIDT), which includes standards and guidelines.

2.2.3 Obtain the Greatest Ecological Benefits for the Financial Cost

The ecological and social values of forests in the CRMW drive their management under the CRW-HCP. Limited allocated funding for upland forest restoration, however, requires that WMD staff be concerned with project efficiency and cost effectiveness. While a standard economic cost/benefit analysis (where costs and benefits are expressed in dollars) is difficult to conduct for ecosystem restoration projects, the relative ecological benefit (see Section 3.3.1) can be evaluated against project costs. An attempt will be made to select potential restoration sites and prioritize among those sites based on criteria designed to achieve the greatest expected ecological benefit (using criteria and methods described in Section 5.0). During individual project planning (see Section 9.0), various treatment options will be compared for expected ecological benefits (e.g., improvement in forest structure, tree growth, species composition, successional processes, and wildlife habitat quality). The treatment with the greatest predicted overall benefit for the least cost will, in most cases, be chosen. Treatments with higher benefits for greater costs, however, may be considered in order to mimic natural disturbance conditions and the forest processes associated with them and to meet the overall goals of the CRW-HCP. Because precise outcomes of treatments are unknown, expected ecological benefits come with some degree of uncertainty. Managing risks in design and evaluation of treatments is essential, and monitoring will be critical for obtaining scientifically sound data on which to evaluate program success and implement adaptive management (see Section 8.0).

2.3 Program Activities

2.3.1 Upland Ecological Thinning

Upland Ecological Thinning consists of thinning dense, relatively homogenous second-growth forest areas generally older than 30 years, with the primary goal of accelerating the development of old-growth forest conditions (see Section 3.1.1). In forest development terms, ecological thinning is actively limiting the time forests spend in the competitive exclusion stage of forest succession while enhancing structural complexity and biodiversity. More specific objectives of ecological thinning include:

- maintain or increase tree diameter growth;
- encourage tree canopy development;
- increase overall species diversity;
- increase structural complexity (e.g., multiple canopy layers, variable tree density, large snags, large downed wood)
- increase spatial heterogeneity;
- accelerate understory development, and;
- improve old-growth forest habitat connectivity at a landscape scale.

Ecological thinning may include thinning of various tree canopy strata, thinning across diameters, creating gaps, and killing or injuring trees to create snags and downed wood or unique features that foster biodiversity. Thinning may also be supplemented by restoration planting (see Section 2.3.3) to increase plant diversity and structural development.

Examples of how thinning may be used to achieve these conditions include:

- creating variable spacing among trees, leaving a diversity of tree diameters and heights, and encouraging several canopy layers;
- creating small openings to recruit a diversity of plant species and stimulate growth of large trees, as well as understory trees, shrubs, and herbs;
- increasing light levels to release co-dominant and intermediate-sized trees and advanced tree regeneration;
- retaining desired species and unique trees; and,
- creating snags, downed wood, tree cavities, and other unique tree features where it is determined they are deficient.

The CRW-HCP has committed to spend $1,000,000 (in 1996 dollars) for implementing ecological thinning (exclusive of WMD staff time), including $31,250 per year for the first 16 years and $14,706 per year for the final 34 years (CRW-HCP: 4.2-36). The CRW-HCP estimated treatment and implementation costs at $500 per acre resulting in base treatment objectivess of 62.5 acres per year for the first 16 years and 29.4 acres per year for the final 34 years (2,000 acres total), though official commitments are in terms of money spent and not acres treated. This level of intervention equates to less than 3 percent of the 71,500 acres of second-growth forest in the CRMW. The cost commitments described above do not include the cost of project design, project administration, or removal of some thinned trees from the site; these additional costs are covered by the SPU budget for this activity. The CRW-HCP allows sale of some trees thinned from ecological thinning projects, however, if ecological objectives are met. The CRW-HCP requires that any revenues from ecological thinning be used to offset the costs of CRW-HCP implementation, which could potentially increase the number of acres that can be restored without increasing the cost.

A 2,000-acre level of ecological thinning intervention over 50 years is unlikely to affect forest habitat on a scale appropriate for the restoration of old-growth forest dependant species on a metapopulation scale, particularly for those species that have home ranges in the thousands of acres (e.g., northern spotted owl, northern goshawk, pileated woodpecker [*Dryocopus pileatus*], fisher [*Martes pennanti*], marten [*Martes americana*]) (Morrison et al. 1998, Smallwood 2001). Based on the current forest conditions and potential value of restoration, our ecological thinning project goals include implementing a project annually on a minimum of 62 acres to a maximum of 500 acres, which translates into 2,000 to 25,000 acres over 50 years or 3 to 35 percent of second-growth forest in the CRMW. Projects of larger sizes also allow for diverse treatments based on specific forest conditions at appropriate patch scales, and provide for more efficient planning in terms of costs per acre. Regardless of the project size or acres treated, net implementation costs to SPU, taking into account the program cost and revenues from sale of some of the thinned trees, cannot exceed the annual budget.

2.3.2 Upland Restoration Thinning

Upland Restoration Thinning is the thinning of dense second-growth forest areas generally less than 30 years of age that have relatively low biological diversity and are in or approaching the competitive exclusion successional stage of forest succession (see Section 3.1.1). As with ecological thinning, the primary goal of restoration thinning is to accelerate the development of late-successional and old-growth forest conditions. More specific objectives of restoration thinning include:

- reduce competition among trees;
- increase light penetration;
- stimulate tree growth;
- reduce long-term fire hazard;
- minimize the chance of catastrophic windthrow, insect, or disease outbreak, and;
- accelerate forest development past the competitive exclusion state to a more biologically diverse stage.

When the tree density of a young forest is particularly high, thinning can have a beneficial effect on biological diversification (Carey and Johnson 1995, Carey and Curtis 1996, Hayes et al. 1997). Prescriptions will vary by site, and will include creating variable spacing and favoring less common species to create a more diverse forest.

The CRW-HCP has committed to spend $2,620,000 (in 1996 dollars) for implementing restoration thinning (exclusive of WMD staff time), including $201,750 per year for the first 8 years and $143,714 per year for the next 7 years (CRW-HCP: 4.2-35). Treatment and implementation costs were estimated at $250 per acre resulting in base treatment objectives of 807 acres per year for the first 8 years and 575 acres per year for the next 7 years (10,480 acres total), though official commitments are in terms of money spent and not acres treated. The cost commitments described above do not include the cost of project design or administration, but these additional costs are covered by the SPU budget for this activity. Currently, our project goals include implementing a restoration thinning project annually on 600 to 1,000 acres, within the constraint that implementation costs do not exceed the annual budget. At this treatment rate, all of the areas that are likely to benefit from restoration thinning are anticipated to be treated in this 15-year period, although some areas will be left untreated intentionally in order to provide a basis for comparison and to allow the currently existing forest development and successional processes to occur.

2.3.3 Upland Restoration Planting

Upland Restoration Planting will be implemented in upland second-growth forest areas to increase the diversity of plant and soil communities made depauperate by past land use and forest practices. The goal of upland planting is to restore appropriate levels of diversity of trees, shrubs, forbs, bryophytes, lichens, and fungi (and other microflora) characteristic of naturally regenerated areas and old-growth forests. Such diversity is expected to support a wide range of native wildlife species and support key ecological processes and foodwebs. Restoration planting may be used to augment other restoration efforts, including ecological thinning, restoration thinning, and road decommissioning. Because the dispersal rates of some flora associated with late-successional forests are low (Muir et al. 2002), planting of these dispersal-limited species in key areas may enhance ecological function and biodiversity at a landscape scale. Planting of some types of these organisms (such as lichens and mosses) has rarely been attempted, making these planting efforts to restore ecosystem components experimental in nature.

The CRW-HCP has committed to spend $300,000 (in 1996 dollars) for implementing upland restoration planting (exclusive of WMD staff time), including $9,375 per year for the first 16 years and $4,412 per year for the final 34 years (CRW-HCP: 4.2-34). Treatment and maintenance costs were estimated at $300 per acre, based largely on the cost of planting tree seedlings, resulting in treatment goals of 31.3 acres per year for the first 16 years and 14.7 acres per year for the final 34 years (1,000 acres total). The cost commitments described above do not include the cost of project design or administration, but these additional costs are covered by the SPU budget for this activity. Since few areas have been determined to be under-stocked with trees, the primary program goals include implementing upland planting to enhance biodiversity in conjunction with ecological thinning projects with nonspecific acre targets. As more is known about planting other species that exist in old-growth forest but are lacking in second-growth (e.g., lichens, mosses), upland restoration planting may evolve more specific treatment goals. The costs of planting species other than coniferous trees are largely unknown, but implementation costs will not exceed the annual budget.

2.3.4 Conceptual Model of Forest Restoration Activity

A first step in implementing the forest restoration programs under the CRW-HCP involves identifying where restoration interventions will and will not occur. Forest that are developing well, provide good wildlife habitat, and have moved beyond the competitive exclusion stage will simply be protected. Those second growth forests that do not fit this criteria and have high stem densities, high relative densities, homogenous forest structure and provide poor wildlife habitat will be candidates for restoration interventions.

The conceptual model for the implementation of forest restoration projects over the chronological age of a forest may include restoration thinning when the forest is 15-30 years old, an initial ecological thinning when the forest is greater than 30 years old, and successive ecological thinnings and upland restoration planting if forest conditions warrant and if final thinning targets (i.e. structurally complex and biologically diverse forests that are moving toward a late successional forest conditions) cannot be achieved with one entry. Given the high degree of uncertainty in our ability to restore second-growth forest to late-successional condition, we will practice adaptive management to identify and question our restoration management assumptions. All three forest restoration activities will be designed to create and maintain mosaics of late-successional forest habitats over a range of spatial and temporal scales, thus providing habitat for a wide range of native organisms and assisting in the development and support of key ecosystem processes (see Section 3.1).

Disturbances on many spatial and temporal scales are natural components of the forest ecosystem in the Pacific Northwest, and restoration treatments will attempt to mimic small-scale disturbance such as windthrow, lightning, disease and insect infestations. Large-scale catastrophic disturbances such as fire, however, may negatively impact both water quality (protection of water quality is the primary goal of the CRW-HCP) and wildlife habitat for species of concern in the CRW-HCP, and the CRW-HCP expressly commits to avoid or minimize catastrophic damage from large-scale disturbances. As a result, if the risk of catastrophic disturbance is considered significant, those forest areas that are considered to be highly susceptible to fire will be given high priority and management intervention will be designed to reduce that risk.

3.0 THEORETICAL FRAMEWORK FOR UPLAND FOREST RESTORATION

Accelerating the development of late successional forest conditions and biological diversity from young, dense, homogenous, second-growth forests is a new field and holds inherent uncertainties in achieving the ultimate goal. In the past few decades, however, managers and scientists have learned a great deal about Pacific Northwest forest ecosystem structure and function, the role of forests in moderating ecosystem processes, and potential solutions to restoring lost ecosystem functions through silvicultural manipulation (Lindenmayer and Franklin 2002). This knowledge evolved as much of the old-growth forest was harvested and replaced by young second-growth forests. Through this evolution of circumstances, land managers and scientists observed the subsequent impacts to site productivity, biodiversity, forest stability, wildlife habitat, and watershed function. Currently, little of the original unmanaged forested landscape remains, by some estimates as low as 13 percent in the Pacific Northwest (Norse 1990), and most of the young forests are simplified in structure and biodiversity. Managers and scientists are attempting to retain and restore complexity to these second-growth forests, while humbly acknowledging that they know relatively little about the many ecological processes that drive those ecosystems. These processes include:

- forest succession and stand development;
- tree growth;
- canopy structural development;
- biological diversification;
- decay;
- below-ground processes; and,
- disturbance.

Experimentation has revealed much about how trees grow and respond to silvicultural treatments, such as thinning and planting, although largely in the context of growing trees for commercial harvest. Knowledge of ecosystem processes that affect tree growth, site productivity, natural forest development, forest diversity and stability, and wildlife habitat is still forming.

Section 3.1 of this plan discusses some of the key ecological processes as they are influenced by different kinds of forest restoration interventions. Current understandings of forest succession are discussed, as this is the key ecological process that is the focus of restoration interventions. This section also discusses how forest structure is known to affect forest ecosystem function, in order to provide a justification for attempts to accelerate the development of certain forest structures. Section 3.2 discusses how intervention can restore forests in conjunction with natural processes. Section 3.3 outlines the risks, benefits, and why we should actively attempt to restore second-growth forests in the CRMW. The state of forest restoration science in the Pacific Northwest is summarized in Section 3.4. Finally, Section 3.5 includes a discussion of knowledge gaps and the key research questions that need to be addressed for an effective adaptive management program.

3.1 Forest Processes, Structure, and Function

Today, most of the forestlands in the Pacific Northwest have been affected by forest management activities and are in relatively early stages of successional development (Muir et al. 2002). These forests typically exhibit low structural complexity, low biodiversity, and high tree densities (Lindenmayer and Franklin 2002). Most of the second-growth forests in the CRMW fall into this category (see Section 4.0). The goal in the Upland Forest Restoration Program in the CRMW (as stated above in Section 1.0) is to increase the diversity and functionality of these forest ecosystems by accelerating the development of late-successional forest conditions. While we can identify late-successional characteristics that we wish to achieve (Franklin et al. 1981) by studying remaining patches of old-growth forest, there is much that we do not know about the process of moving from a young, structurally simplified forest to an ecologically complex forest through active restoration. The one factor that clearly plays a role in developing late-successional characteristics is time (Spies 1997)!

Old-growth forests may be qualitatively and quantitatively described by their structural characteristics (Franklin et al. 1981), stand development processes (Oliver and Larson 1996), or by ecological processes and their associated temporal scales (Franklin et al. 2002). Common definitions of old-growth cite 150 to 250 years as a sufficient temporal window to produce forests that exhibit typical late-successional characteristics (e.g., large trees, large snags, large downed wood, patchy tree distribution, multiple canopy layers, relatively high biodiversity), although this range may vary widely depending on forest species composition (Spies 1997). Forest restoration efforts attempt to increase the structural complexity and biological diversity and accelerate the development of old-growth forest conditions that are lacking in today's second-growth forest landscape in order to provide better habitat for species dependent upon these features.

3.1.1 Forest Succession

By definition, forest succession is the natural pattern of ecosystem growth and change over time following major disturbance events like wildfire, windthrow, or clearcut timber harvesting. The process of forest development and succession, including establishment, growth, and decay, facilitates a host of ecological processes and functions (see Sections 3.1.2 and 3.1.3). Attempts to influence forest development and accelerate forest succession will affect and be affected by these ecological processes.

Several models describe the forest succession pathway that Pacific Northwest forests may follow over time (Oliver and Larson 1996, Franklin et al. 2002) and can be used to guide forest restoration efforts. A model widely cited for Pacific Northwest coniferous forests depicts four simple stages of forest development following a catastrophic stand-replacing disturbance (Oliver 1981). These four successional stages are:

- stand initiation;
- competitive exclusion (stem exclusion);
- understory reinitiation, and;
- old-growth.

This model applies to relatively even-aged (or single cohort) forest areas where all the dominant trees establish within a few decades of each other following a major disturbance (Oliver and Larson 1996). Forest successional dynamics described by Oliver's model (1981) apply to a great proportion of previously managed forests in the Pacific Northwest and elsewhere.

3.1.1.1 Stand Initiation Stage

The *stand initiation* stage of Oliver's model (1981) occurs immediately following a disturbance when light, soil moisture, and nutrients are readily available for plant establishment and growth. This successional stage supports high species diversity, although most of the plant and animal species have fairly general habitat requirements, unlike many species that inhabit late-successional forests. This successional stage may last for one year to several decades depending on the disturbance type and intensity, soil and site characteristics, pre-existing forest conditions and biological legacies, and the seeds and propagules that facilitate establishment of new biota. Forest composition is dictated by patterns of disturbance and physical environmental constraints (elevation, slope, aspect, soils, climate), by biological forces (such as legacies from prior forest, soil microbial communities, and so forth), and whether active reforestation (tree planting) has occurred (Franklin and Dyrness 1973, Henderson and Peter 1981). All these factors affect forest establishment, species composition, and the resulting forest development and structure. The density of tree seedlings that establish during stand initiation will determine the degree of competition among trees during the next stage of forest succession (Tappeiner et al. 1997).

3.1.1.2 Competitive Exclusion Stage

As the trees that established during the stand initiation stage begin to grow, their crowns and root systems overlap and they begin to compete for resources (e.g., light, water, nutrients). Thus begins the *competitive exclusion* or *stem exclusion* stage, which may last a couple of decades or approach a century in length depending on tree density, soil productivity (e.g., site class), and other environmental characteristics. Throughout this successional stage, most of the available light is captured in the upper tree canopy layer. Few plants are able to establish in the understory once canopy closure has occurred, resulting in relatively low species diversity. Similarly, because the majority of foliage is distributed in one stratum (the main canopy layer), structural complexity during this successional stage is very low. Trees eventually differentiate into crown classes and assume dominant, co-dominant, and subdominant (intermediate and suppressed) canopy positions within the main canopy stratum (Figure 1). Crown differentiation depends on tree genetics and microsite factors. The dominant trees capture the most light, while the co-dominant and subdominant trees have progressively less light. Accordingly, the dominant trees exhibit the most rapid growth in both height and diameter. Some species, however, especially those that are more shade tolerant, are able to continue sustained height growth so that species dominance may change as the forest continues to develop. As competition intensifies, some intermediate and suppressed trees die and become snags and downed wood. The tree density begins to decline in this successional stage as the forest self-thins through competition mortality. Mortality during this successional stage tends to lead to a uniform spatial pattern, minimizing competitive interactions between trees (Kenkel 1988). Forest restoration in the CRMW seeks to limit the time spent in this successional stage and increase the complexity and diversity to levels that are comparable to later successional stages of forest development.

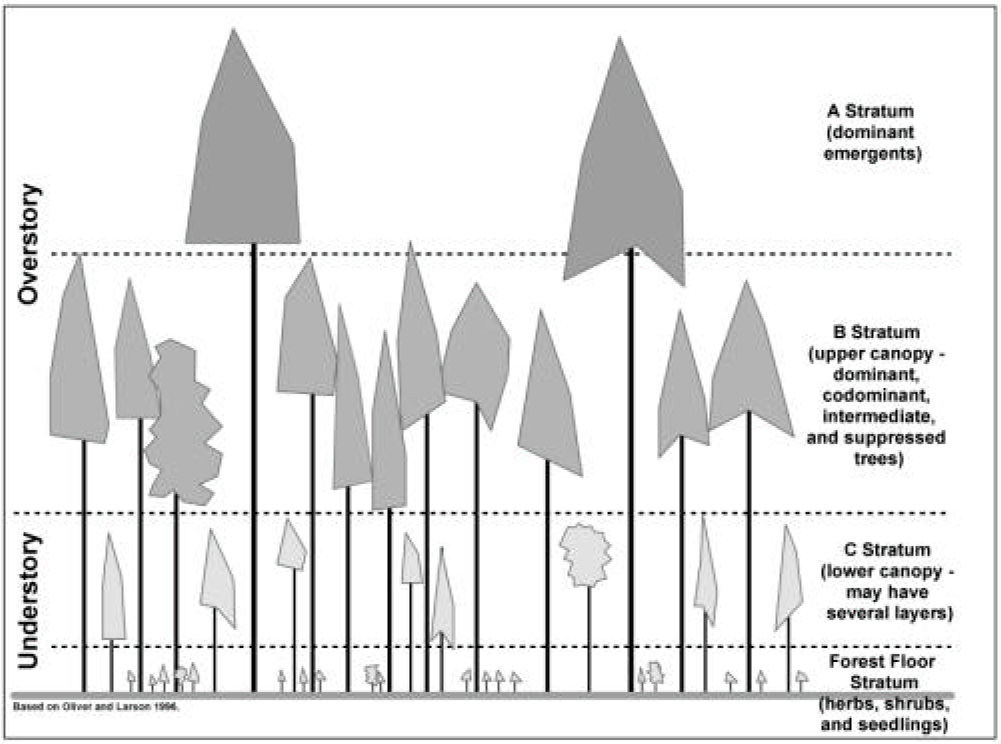
3.1.1.3 Understory Reinitiation Stage

As mortality occurs in the forest stand and tree density diminishes, light penetrates through the upper forest canopy (the highest stratum) and reaches the forest floor. At this point, *understory reinitiation* begins, because there is enough light for shade-tolerant tree seedlings, shrubs, and herbs to establish and grow slowly in the understory. This successional stage may last 100 years. Canopy density continues to diminish throughout this stage due to mortality of some overstory trees as well as crown abrasion among neighboring trees.

3.1.1.4 Old-Growth Stage

As the forest continues to mature, overstory trees begin to die from causes other than competition, such as root rot diseases, insect attack, and windthrow. The pattern of mortality is less uniform, and gaps begin to form in the forest canopy. The forest has entered the *old-growth* *stage* where *gap phase dynamics* tend to dominate. These gaps allow more light to penetrate through the forest canopy, and some of the plants that have established on the forest floor begin to fill in these gaps and grow more quickly up toward the main canopy. As overstory trees

Figure 1. Conceptual model of forest canopy strata.



continue to die, the forest becomes more patchy, shade-tolerant plants begin to increase in number and size, large snags and downed wood are created as the large overstory trees die, and the forest begins to increase in structural complexity. Vertical complexity (or heterogeneity) increases because the forest is no longer dominated by one stratum of the original cohort of trees, but rather contains multiple strata from the overstory down through the middle canopy to the forest floor. Similarly, horizontal complexity (or heterogeneity) is increased due to the gaps and retained patches of overstory trees. This stage can continue as a shifting mosaic of complexity until another major disturbance event.

Though this model has great applicability, especially with the inherent uncertainty of forest ecology and restoration, it is somewhat simplistic (Oliver and Larson 1996). First, the model does not necessarily distinguish between the type of disturbance that starts the successional process, which can result in very different starting conditions (Oliver et al. 1985, Tappiner et al. 1997, Franklin et al. 2002, Winter et al. 2002a). Wildfire, for instance, will not likely kill every large tree in an area, and clearcut timber harvesting is often followed by replanting. Regenerating forests in these conditions would be significantly different. Second, all forests do not fit neatly into the four successional stages or proceed linearly along the successional path (Stewart 1986, Holah et al. 1997). In reality, there are multiple pathways of forest succession (Hunter 2001). Finally, the model does not clearly address the subtleties of mature and old-growth forest development and the processes that work to create these highly complex forest structures (Franklin et al. 2002).

3.1.1.5 Successional Model Complexity

To redress some of the simplicity of the Oliver four-stage conceptual model of forest succession, an eight-stage model was developed based on key ecological processes (Franklin et al. 2002). This more complex model focuses on the processes that develop forest structures as they relate to biological diversity and productivity rather than distinct successional stages as typified in the Oliver model (1981). Additionally, it describes in detail the role of biological legacies following disturbance, the role of dead wood, and the development of spatial heterogeneity in forests. It also expands upon the processes that occur in the development of late-successional forest characteristics and how managers might focus on those key processes in their attempts to accelerate the development of these characteristics. Table 1 summarizes forest structural features considered in the model, while Table 2 notes many of the ecological processes associated with the development of those features over time.

Table 1. Structural features of forests (adapted from Franklin et al. 2002).

Individual Structures	**Variation in Structures**
Live trees	Species, density, mean diameter, range in diameter, height, canopy depth
Large-diameter live trees	Species, density, decadence, crown condition, bark characteristics
Large-diameter branches	Species, density, size, individual or arrays, presence of arboreal "soil"
Lower-canopy tree community	Composition, density, height
Ground community	Composition, density, deciduous/evergreen
Standing dead trees (snags)	Species, size, decay state, density
Downed wood	Species, density, decay state, volume, mass
Uproots (root wads and holes)	Density, size, age
Organic layers	Depth, chemical and physical properties, biota
Spatial Patterns	**Variation in Spatial Pattern**
Vertical distribution of foliage/canopy	Depth, continuity, cumulative distribution
Horizontal distribution of structures	Spatial pattern (e.g. random, dispersed, aggregated)
Gaps and skips	Size, shape, density

The processes that are described in Table 2 are categorized into eight successional stages, which are highlighted in bold. These successional stages are very similar to those outlined by Spies and Franklin (1996), and both models address processes associated with old-growth forests (greater than 300 years old) to a greater extent than other models (Bormann and Likens 1979, Oliver and Larson 1996, Carey and Curtis 1996).

The successional model posed by Franklin et al. (2002) separates Oliver's competitive exclusion stage into *canopy closure* and *biomass accumulation*/*competitive exclusion* stages. In dividing the competitive exclusion stage into early and late developmental aspects, they differentiate the processes of canopy closure, where dramatic climatic changes occur within the forest, from the continued growth of dominant and co-dominant trees. Since many natural forests establish at lower densities than typically found in a managed (e.g., replanted) landscape (Tappeiner et al. 1997), the authors focused on the importance of biomass accumulation in this stage rather than the more commonly cited process of competition mortality. It is during this stage of forest development that trees attain their most rapid diameter and height growth. The process of biomass accumulation is central to forest ecosystem development and function, and it is one process that forest restoration attempts to mimic in order to accelerate the growth of large trees in densely stocked forests.

Table 2. Ecological processes associated with the successional development of forests (adapted from Franklin et al. 2002).

Forest Age (yrs)	Forest Processes
0	Disturbance and Legacy Creation
	Establishment of a new cohort of trees/plants
20+	**Canopy Closure by Tree Layer**
	Competitive exclusion of ground flora
	Lower tree canopy loss (death and pruning of lower branches) – canopy lift
30+	**Biomass Accumulation**
	Density dependent tree mortality (competition/thinning mortality)
	Density independent tree mortality (wind, disease, insects)
50+	**Canopy Gap Initiation and Expansion**
	Generation of downed wood and snags
	Uprooting (ground and soil disruption and creation of structures)
	Understory redevelopment (shrub and herb layers)
	Establishment of shade-tolerant trees (assuming pioneer cohort is intolerant species)
	Shade patch (anti-gap) development
80+	**Maturation of Pioneer Tree Cohort** Maximum height and crown spread
150+	**Canopy Elaboration (Vertical Diversification)**
	Development of multi-layered canopy
	Growth of shade tolerant trees into co-dominant canopy position
	Re-establishment of lower branch systems on intolerant dominants
	Development of live tree decadence (multiple tops, dead tops, bole and top rots, cavities, brooms)
	Development of large branches and branch systems
	Associated development of rich epiphytic communities on large branches
300+	**Horizontal Diversification**
800+	**Pioneer Cohort Loss**

The understory reinitiation stage is similarly divided between the biomass accumulation and *maturation* stages, illustrating that as competition mortality occurs and the surviving trees attain their maximum height and crown spread, the establishment of herbs, shrubs, and shade-tolerant trees is also occurring on the forest floor. During the maturation stage, density-independent mortality processes, such as root rot and insect outbreak, take precedence over competition mortality. This stage also exhibits low levels of downed wood and an increased development of decadence in overstory trees. The maturation stage often begins 80-100 years and may persist until 180-250 years.

Following maturation, forests move into the late-successional stages of *vertical diversification, horizontal diversification*, and eventually *pioneer cohort loss.* During vertical diversification, there is "re-establishment of canopy continuity between the ground and upper tree crown" (Franklin et al. 2002). This process occurs both through the upward growth of shade tolerant understory trees and downward expansion of Douglas-fir (*Pseudotsuga menziesii*) tree crowns through epicormic branching (Ishii and Wilson 2001). Both of these processes are stimulated by increased light due to the thinning canopy. Downed wood tends to increase, canopy gaps are initiated and expanded, and the biomass of lichens and bryophytes increases. In the horizontal diversification stage, canopy gaps continue to expand such that the forest becomes a series of structural patches. Franklin et al. (2002) indicate that the horizontal diversification begins to dominate old-growth forest structure after about 300 years. However, one reconstruction of an old-growth Douglas-fir forest in western Washington found canopy disturbances, which contribute to horizontal heterogeneity, distributed throughout the developmental history of the forest area (Winter et al. 2002b). The pioneer cohort loss stage occurs when the original shade-intolerant pioneers have declined in number and the same species is unable to effectively regenerate in the forest understory.

While the chronological development of structures and processes in old-growth forests is informative, our forest restoration efforts will primarily be targeting forests in earlier successional stages. Younger forests currently dominate the CRMW landscape and have relatively uniform forest structure. Restoration will attempt to set the stage for the developmental processes defined by Franklin et al. (2002) to occur more rapidly, in particular the processes of biomass accumulation, understory reinitiation, and vertical and horizontal diversification. These restoration efforts will be implemented with the understanding that we are not trying to create any particular successional stage but rather develop the forest structures, foster ecosystem processes, and increase the level of complexity that is evident in late-successional forest ecosystems.

3.1.2 Tree Growth and Canopy Development Processes

Individual tree growth and interspecies interactions vary throughout forest succession (Franklin and Dyrness 1988). In the stand initiation stage, pioneer species that have a ready seed source and grow quickly will tend to dominate the site. In the CRMW these species include shade intolerant Douglas-fir, red alder (*Alnus rubra*), and noble fir (*Abies procera*) at higher elevations. As these pioneer species grow into the competitive exclusion stage, they compete with each other for growing space and resources. Deciduous trees typically have a relatively short life span, regardless of shade tolerance (Table 3), so they usually yield the site to conifer dominance. Entering into the understory reinitiation stage, shade-tolerant tree species (e.g., western hemlock [*Tsuga heterophylla*], Pacific silver fir [*Abies amabilis*], western redcedar [*Thuja plicata*]) are able to establish in the understory, and may eventually, over hundreds of years, dominate the stand over the long-lived shade-intolerant species (e.g., Douglas-fir and noble fir). Though the conceptual model of a shifting-mosaic old-growth forest includes all of these species, depending on forest type and the frequency and severity of disturbance, some old-growth forests can develop into a monoculture of long-lived shade-tolerant species (e.g., western hemlock, Pacific silver fir).

The development of individual tree foliage in the canopy and canopy layering also varies within the forest successional process (Franklin et al. 2002). In the stand initiation stage or in more open conditions (e.g., at forest edges), trees develop branches along the length of their boles. In the competitive exclusion stage, lower branches of shade intolerant trees will eventually die as they become shaded by neighboring trees. In forests where this stage lasts a relatively long time, live branches (also known as "live crown") become confined to the upper portions of the tree bole. Trees with very little live crown (i.e. less than 30 percent) are less able to respond to available light in the event of a disturbance to surrounding forest canopy. The understory reinitiation stage brings more light and allows individual trees crowns to expand in both width and depth. Some species produce epicormic branches in response to increased light (Ishii and Ford 2001). The forest canopy diversifies in this stage through the addition of a lower canopy from a new cohort of trees. Old-growth forests typically have large trees with branches in the upper canopy (or throughout the bole for those species capable of producing epicormics) and several canopy layers.

Table 3. Ages and dimensions typically attained by trees on better sites in the Pacific Northwest (based on Franklin and Dyrness 1988).

Tree Species		Age (yrs)	Diameter (")	Height (')	Shade Tolerance
Pacific silver fir	*Abies amabilis*	400+	35-45	150-180	Very tolerant
Grand fir	*Abies grandis*	300+	30-40	130-200	Tolerant
Subalpine fir	*Abies lasiocarpa*	250+	20-25	80-115	Tolerant
Noble fir	*Abies procera*	400+	40-60	150-230	Intolerant
Sitka spruce	*Picea sitchensis*	800+	70-90	230-250	Tolerant
Western white pine	*Pinus monticola*	400+	40-45	200	Less tolerant w/ maturity
Douglas-fir	*Pseudotsuga menziesii*	750+	60-90	230-265	Intolerant
Western redcedar	*Thuja plicata*	1,000+	60-120	200	Tolerant
Western hemlock	*Tsuga heterophylla*	400+	35-50	165-215	Very tolerant
Mountain hemlock	*Tsuga mertensiana*	400+	30-40	80-115	Tolerant
Bigleaf maple	*Acer macrophyllum*	300+	20	50	Tolerant
Red alder	*Alnus rubra*	100	20-30	100-130	Intolerant
Black cottonwood	*Populus trichocarpa*	200+	30-35	80-115	Intolerant

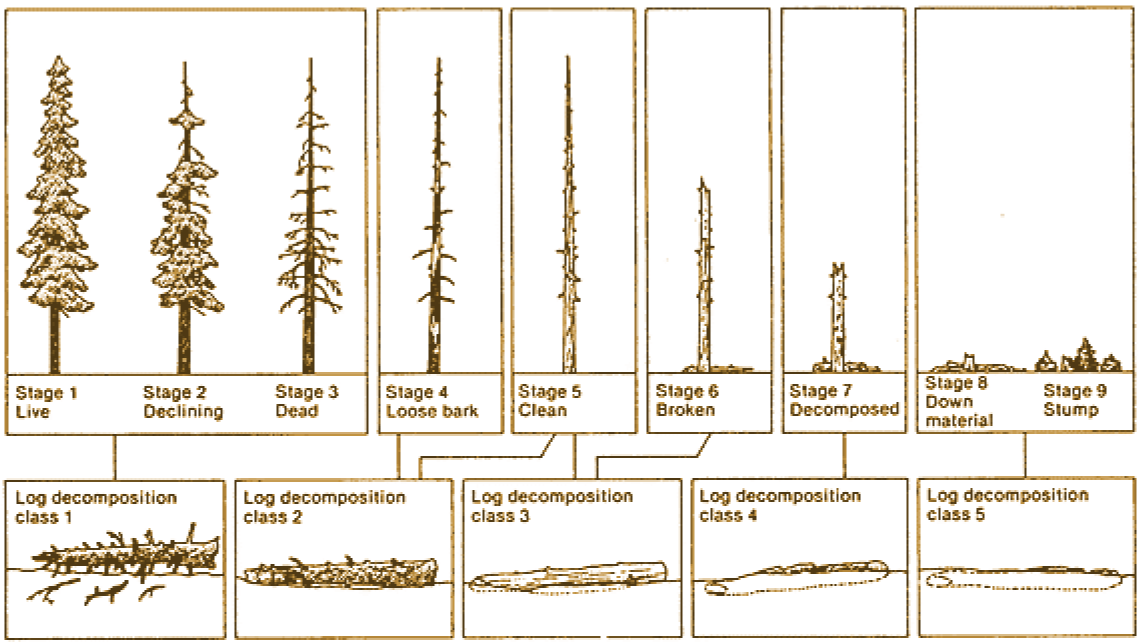
3.1.3 Tree Mortality and Decay Processes

The processes of tree mortality are directly linked to the forest successional process. There is little tree mortality in the stand initiation stage. However, the competitive exclusion stage is dominated by the process of density-dependent mortality. As trees grow at high stem density, they compete for the available sunlight, water, and nutrient resources; some trees continue to grow and prosper while others become stressed from the lack of resources and ultimately die. Density-independent mortality processes take precedence in the understory reinitiation and old-growth stages, due to insects, disease, windthrow, snow, and fire.

Standing dead trees, or snags, provide an important habitat niche for wildlife (Johnson and O'Neil 2001) as they undergo the process of decay. Initially standing tall and relatively hard, over time snags break apart and soften (Figure 2). Eventually they fall to the ground to become downed wood and continue to decay. Ultimately, they break down to be a valuable nutritional component of forest soil and the carbon that was trapped in the living biomass gets released through microbial respiration back into the atmosphere.

The large snags and downed wood of old-growth forests provide different and longer lived habitat niches than the small snags and downed wood of forests in the competitive exclusion stage of forest development. Relatively large tree cavity nesters (e.g., pileated woodpecker, northern spotted owl, northern flying squirrel [*Glaucomys sabrinus*]), for instance, physically cannot inhabit cavities in smaller trees. The volume of a single old-growth log can dwarf the volume of all downed wood in a younger stage and provide the appropriate temperatures and moisture levels for amphibians and invertebrates

Figure 2. Snag stages and downed wood decay classes.



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3.1.4 Understory Development Processes

Understory development processes, or the shrubs, herbs, and other vegetation growing under a tree overstory, are also linked to the process of forest succession. Fast-growing pioneer shrub and herb species dominate the beginning of the stand initiation stage, but they are eventually overtopped by trees and are all but eliminated in the competitive exclusion stage as the tree canopy closes. As trees die and the canopy opens again, the depauperate understory is populated by species that have a ready seed source. Common understory vegetation of forests in the CRMW includes salal (*Gaultheria shallon*), swordfern (*Polystichum munitum*), vine maple (*Acer circinatum*), and huckleberry (*Vaccinium spp.*). The abundance of these and other understory species are largely determined by site. Salal can dominate the understory through its prolific rhizomatous growth and can limit the diversity and abundance of other species. The shifting-mosaic of old-growth forests can maintain a dynamic and diverse understory community, however, some old-growth forest may have a relatively depauperate understory limited by a dense overstory and unproductive soils.

3.1.5 Other Ecological Processes

There are more ecological processes that occur in forest ecosystems than we can either describe in detail or measure in the field. Clearly, forest restoration activities will affect many, if not all, ecological processes that are dependent upon forest structure and function in the forested landscape. However, the scientific community cannot begin to describe all those processes. There are certain general ecological processes and cycles that forest development affects, and because the forests themselves are part of those cycles, they are in turn affected by them. Below are several of the more significant and well-known ecological processes. A discussion of these processes provides the foundation for understanding how forest restoration efforts may affect these processes and vise versa. It does not imply that all of these processes will be measured as we attempt to restore forests toward late-successional conditions in the CRMW.

3.1.5.1 Food Webs

Primary production is the conversion of CO_2 and solar energy to biomass. Because they contain chlorophyll, the power source of photosynthesis, green plants and cyanobacteria are the primary producers of our planet. The solar energy and carbon that chlorophyllus plants capture are then passed along the food chain to herbivores (primary consumers), carnivores (secondary consumers), omnivores, detritovores (eating dead organic material), and eventually decomposers (feeding on byproducts of decaying organic material) (Kimmins 1987, Marcot et al. 1997). Much of the energy and carbon is lost along the food web, although significant portions also become incorporated into the soil ecosystem that then supports continued plant growth.

Herbivores can significantly influence the rate of succession or the plant species composition in an ecosystem (Muir et al. 2002), whether those herbivores are elk, moths, or bark beetles (Marcot et al. 1997). Similarly, carnivores can affect the population levels of herbivores, and therefore affect the plant species composition in an ecosystem. There are many other mechanisms by which organisms partake in energy and carbon captured by plants, including those employed by achlorophyllus plants, which associate with mycorrhizal or saprophytic fungi to obtain carbon from plants. Achlorophyllus organisms also include many parasites and most decomposers. Similar to the effects of herbivores in shaping plant communities, both mycorrhizal and pathogenic fungi can affect the establishment, growth, and decline of certain plant species.

3.1.5.2 Soil, Nutrient Cycling, and Below-Ground Processes

Soil productivity dramatically affects the plant community and associated organisms and processes that may thrive on a site (Perry et al. 1989). Soils are dynamic ecosystems that comprise physical, chemical, and biological elements and processes. The process of soil development is influenced by five factors: parent material (geology), climate, topography, living organisms, and time (Brady 1990). Parent material affects the ultimate physical and chemical properties of soils, including soil texture, structure, moisture holding capacity and fertility. Climate affects the weathering rates of parent materials into soil, as temperature and moisture greatly influence soil development. Topography determines the climatic regime and also the physical forces acting upon parent materials and soils. For example, gravity associated with steep slopes will move soil particles down slope, thereby affecting the soils from which particles have been removed and those where soils have been deposited. Living organisms breakdown rock and mineral particles through the release of organic acids, and therefore play a critical role in creating soils. Carbon that is deposited on or in soils from plant litter, death of living organisms, excretions, and plant root exudates work to build up the soil nutrient base and increase the water holding capacity of soils. Time is the final essential ingredient in soil formation. Soils may take hundreds of thousands of years to develop. The recently glaciated soils in the Puget Sound region are considered to be quite young at 10,000-12,000 years old.

Not only do soils house a great deal of biodiversity (Amaranthus et al. 1989), but they moderate ecological processes, such as nutrient cycling, carbon storage, and water flow through a forested watershed like the CRMW. Vibrant communities form around tree root systems, where 30-70 percent of the carbon that is fixed through photosynthesis is sent (Grier et al. 1981). This rich zone of activity, known as the rhizosphere (i.e., root zone), supports life from mycorrhizae to invertebrates. Organic nutrients (e.g., carbon, nitrogen, phosphorous, potassium, sulfur) cycle through soils from live vegetation that eventually dies. Nutrients from dead vegetation (including snags and downed wood) decompose back to soil and air and are cycled into live material again. Forest soils provide one of the major pools of carbon in the forest carbon cycle (Smithwick et al. 2002).

For practical purposes, soils are typically described by the hillslope on which they are located, their source material, their tendency to erode and/or hold water, and the associated vegetation that they normally support. On a scale of I to V, site class is a general measure of how productive soils are in terms of growing trees, with site class I being very productive and supporting relatively large trees, especially in terms of height, and site class V being not very productive and supporting relatively smaller trees. The tree density of similarly aged mature forests tend to be lower on higher site class soils (e.g., site class I) because the trees are more easily able to differentiate during the competitive exclusion stage of forest succession than those on lower site class soils. Some forest areas on low site class soils may "stagnate" in the competitive exclusion stage for decades.

3.1.6 Forest Structure and Function

Forest structure describes the physical form that the plant community exhibits. For example, old-growth forests of the Pacific Northwest include the following structures:

- diverse tree sizes, including large trees (both in terms of diameter and height);
- vertical structural complexity (e.g., multiple canopy layers or continuous canopy);
- horizontal structural complexity (e.g., patchiness, gaps, variable tree density);
- species diversity (e.g., understory plants, deciduous and conifer trees);
- large snags and downed wood, and;
- landscape connectivity.

Forest structure affects forest function by regulating ecosystem processes and biological diversity (Figure 3). For example, the structural component of snags in a forest provides the function of wildlife habitat for primary and secondary cavity nesters and invertebrates (McComb and Lindenmayer 1999). Similarly, the structural component of downed wood provides the functions of wildlife habitat for a variety of invertebrate and vertebrate species, seedling establishment sites (e.g. nurse logs) (Harmon and Franklin 1989), soil replenishment (carbon and nutrient cycling), and slope stability (Harmon et al. 1986, McComb and Lindenmayer 1999). Complex crown structures, multiple canopy layers, and varied tree and shrub species all contribute to ecological functions, ecological processes, and biological diversity (Spies 1997).

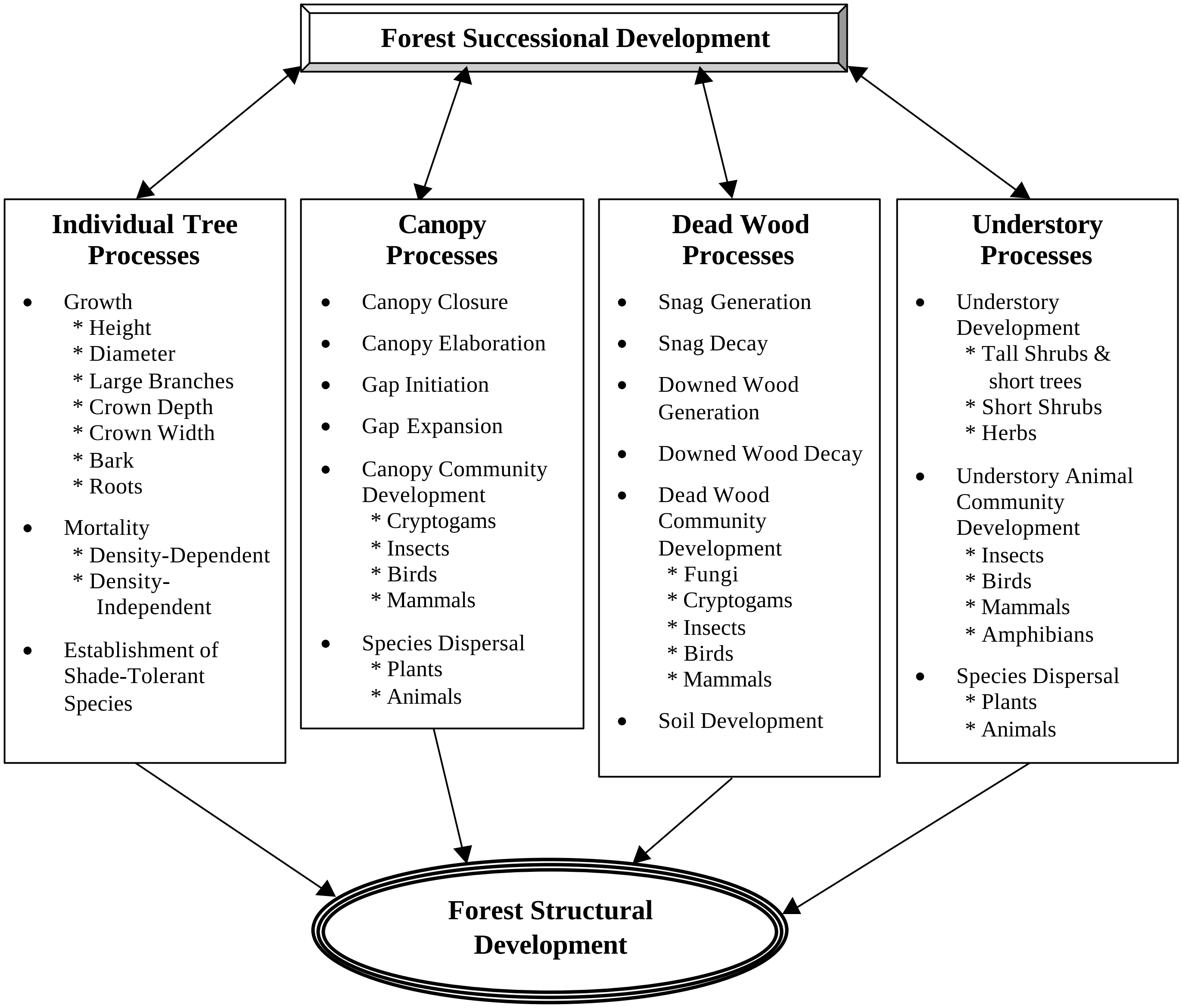
Our forest restoration activities will be designed to create, or at least accelerate the development of, these structural features. A discussion of several key late-successional forest structural characteristics and their associated ecological functions follows.

Large conifer trees capture photosynthetic radiation with full crowns supporting high leaf area and convert that solar energy to useable biomass (Kimmins 1987). This biomass then drives forest ecosystems by providing habitat for a myriad of life forms, including invertebrates, vertebrates, fungi, and bacteria. Large trees provide habitat in their crowns, stems, and root systems. Canopy invertebrates, lichens, plants, and associated wildlife species are currently being researched as scientists achieve access into these once unapproachable realms. Similarly, the root systems of trees support an incredibly rich soil ecosystem through the large amounts of carbon that is transported to roots, mycorrhizae, and associated soil communities. In turn, the trees are inextricably dependent on these soil communities for nutrition and protection from disease. The stems of trees house bats under rough bark (Christy and West 1993) and provide residence for a myriad of cryptogams and invertebrates. Stems also provide the foundation for communities of fungi and invertebrates in heartwood and sapwood. Even when dead, the captured carbon in these trees is recycled through countless life forms as trees decay and replenish the soil ecosystem.

The presence of various sizes of trees, shrubs, herbs, snags, and downed wood provides structural complexity and spatial heterogeneity over various spatial scales. The diversity of canopy layers is directly linked to the biological diversity of forests. The existence of multiple canopy layers of vegetation, from the 150-foot overstory trees to herbs only a few inches tall, affects light, rain, and nutrient penetration from above, which affects how plants compete for these resources and grow. Patchiness, or non-uniform distribution of structure on the landscape, increases complexity. This complexity, in turn, affects niche habitat availability (e.g., roost areas, nest sites, and foraging success) which enhances biological diversity.

Diverse tree and shrub species provide unique habitat niches for many life forms (Muir et al. 2002), effect unique chemical changes on soils (Zinke 1962), and provide a vital component for water moving through forest ecosystems (Edmonds et al. 1991). Plant diversity in a forest provides different food sources for invertebrates, vertebrates, and microscopic organisms. A diversity of species provides ecosystem resistance to insect and disease outbreaks, and may increase ecosystem resilience in the face of global climate change and other large-scale disturbances such as wildfire.

Figure 3. Conceptual model of the integration of forest successional processes and forest structural development.



Large snags and downed wood found in late-successional and old-growth forest provide many ecosystem functions that relatively small snags and downed wood found in competitive exclusion stage forests do not provide including habitat, soil replenishment, and establishment sites for trees. Though remnant snags and downed wood of large size may exist in second-growth forests as legacies from previous old-growth, they are usually in an advanced state of decay in forests in the competitive exclusion stage. Over 130 wildlife species use large snags and downed wood in the CRMW for some part of their natural history (Johnson and O'Neil 2001), including primary and secondary cavity nesters (e.g., pileated woodpecker and northern flying squirrel), detritivores (e.g., carpenter ants [*Camponotus spp*]), and species that use dead wood for foraging (e.g., brown creeper [*Certhia americana*] and Trowbridge's shrew [*Sorex vagrans*]). Organic material from the decay of dead wood and other plant material in general is vital to soil ecosystem function, in that it provides an input of soil nutrients and improves soil moisture holding capacity and soil structure, which affect plant growth as well as soil processes, community composition, and biological diversity.

The juxtaposition or structure of habitat across the landscape affects the movement of wildlife, water, and energy through the system. Habitat connectivity is one of the variables in providing for stable wildlife populations (Pulliam 1988, Wiens 1997, Richards et al. 2002). Habitat diversity may be linked to ecosystem stability, which includes both resistance to change and resilience in the event of change (Perry and Amaranthus 1997).

3.2 How to Restore Second-Growth Forests?

Again, the one factor that clearly plays a role in developing old-growth forest conditions in second-growth forests is time. To shorten the time of development of late-successional forest characteristics in second-growth, Lindenmayer and Franklin (2002) recommend using multiple intervention techniques to create structural complexity and compositional diversity, including:

- thinning to grow large diameter trees;
- variable density thinning (creating skips and gaps, as well as varying spacing between trees);
- thinning from "above" by selectively removing some dominant trees or branch pruning to sustain or release shade-tolerant understory trees and understory shrubs and herbs;
- conservation of tree or other plant species that fulfill different structural and functional roles (i.e., deciduous trees, and species with edible fruits, distinctive bark or branching, or high capacity to host epiphytes);
- conserving and creating decadence (snags, downed wood, cavities); and,
- planting desired tree or understory species.

While forest restoration is a relatively recent science and many of the techniques are considered experimental, many studies indicate that thinning trees in younger forests can accelerate the development of late-successional forest conditions from earlier successional stages (Lindh and Muir 2004, Tappeiner et al. 1997, Carey et al. 1999b, Garman et al. 2003, Anonymous 2003) up to 100 years (Carey et al. 1999). Table 4 summarizes how specific techniques can be used to achieve the ecological objectives of forest restoration projects in the CRMW. Figure 4 presents a conceptual model of the effects of restoration programs in the CRMW on ecological processes. One of the primary methods, as shown above, is forest thinning. This technique may be applied in a variety of ways and will be combined with restoration planting of common and uncommon species in the CRMW.

Enhancing forest structure by thinning, creating snags and large downed wood, creating gaps, retaining untreated areas and planting a variety of species, are focused primarily on influencing forest processes. A dominant process that forest restoration techniques attempts to affect is forest successional development, where accelerating the development of heterogeneous forest conditions is the objective (Franklin et al. 2002). A primary result of thinning will be the maintenance or enhancement of the growth rate of the dominant trees, thereby creating bigger trees faster (Smith et al. 1997). Along with this improved tree growth, other process will be enabled such as increased structural complexity of individual trees crowns (e.g., crown width, depth, and branch size), which may then provide habitat for a greater array of organisms (e.g. epiphytes, marbled murrelet). Other processes that may be affected by forest restoration treatments is the dispersal of organisms, such as lichens, heart rot fungi, and mistletoe, all of which play an important role in forest ecosystem function and foster biological diversity.

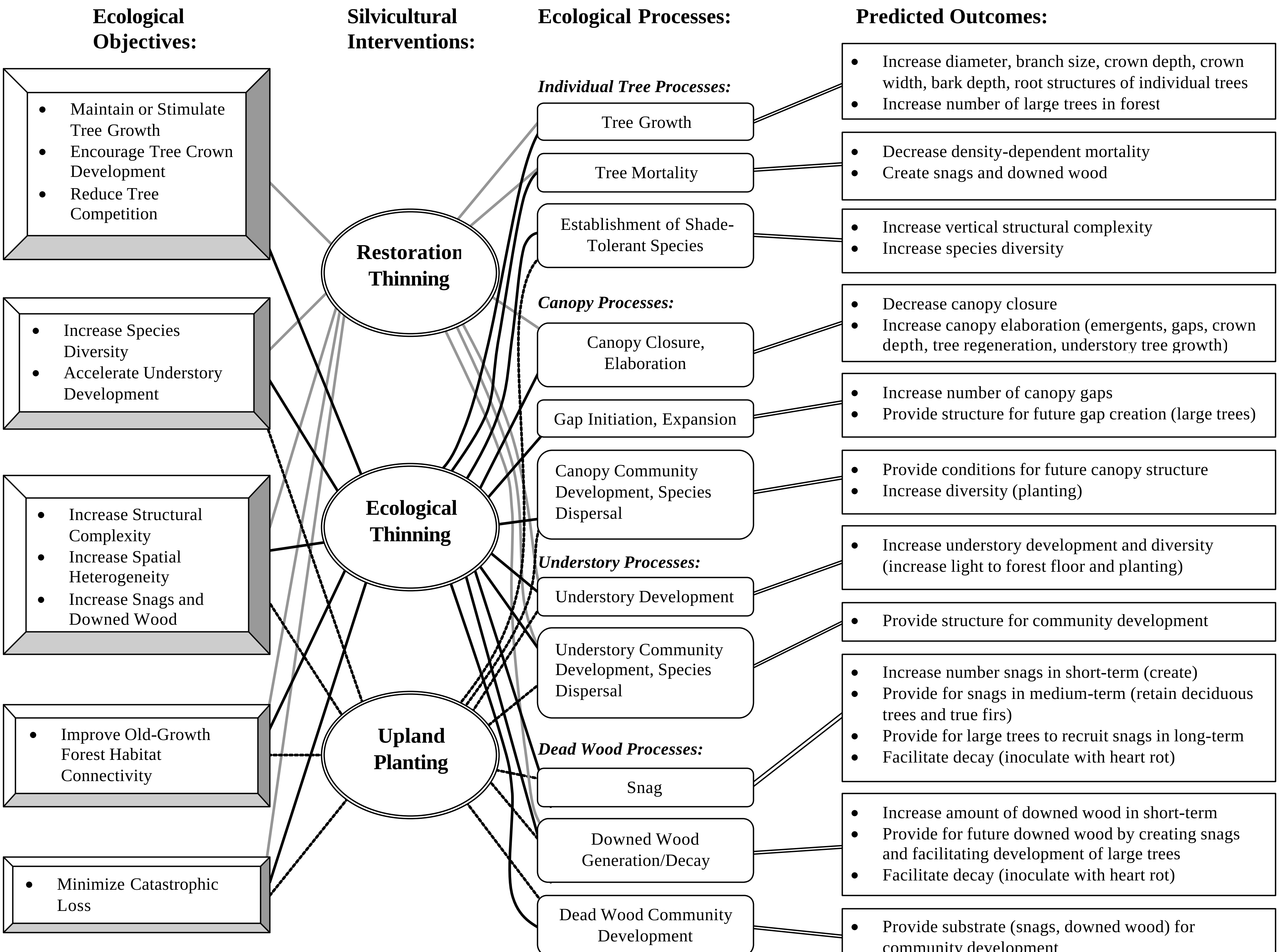
Ecological and restoration thinning will likely generate amounts of downed wood on a scale greater than is typically found in old-growth forest, but potentially analogous to a severe windthrow event or other natural disturbance. Though downed wood is a natural component of a functioning forest, large volumes may increase the hazard of catastrophic fire (Brown et al. 2003), limit understory development (Halpern and Spies 1995), increase the likelihood of insect damage (Furniss et al. 1979), and provide barriers to ground movement for some wildlife species (e.g., elk and deer) (Ripple and Larson 2001). Removing some of this wood, while enhancing pre-thinning levels and maintaining appropriate amounts for ecological function, will minimize potentially negative impacts of large amounts of downed wood and provide a revenue source for increasing the areas treated with ecological thinning and restoration planting techniques to meet forest ecosystem restoration goals. Increasing the structural complexity, biological diversity and accelerating late-successional forest conditions on a larger scale in the CRMW will have significant benefits to populations of late-successional forest dependent wildlife species, especially those with larger home ranges.

It is often pointed out that forests under 50 years old can most benefit from thinning (Hunter 2001) because younger trees are more likely to be able to respond positively to thinning treatments. The appropriate criteria for deciding whether thinning can provide overall ecological benefits as a forest restoration technique, however, is not age, but rather the structural condition of the forest and the ability of the trees to respond positively to a thinning, without unacceptable risk of windthrow. Conifers having grown at relatively high density for many decades can have insufficient crowns and roots to take advantage of the increased light. If the live crown has receded due to competitive interactions, forest thinning may not result in increased tree growth. Additionally, the remaining trees may fall down when exposed to winds if their height to diameter ratio is too high (over 70) (Oliver and Larson 1990). On the other hand, forests as old as 110 and 650 years have responded favorably (e.g., better tree growth) to density reduction (Williamson 1982, Latham and Tappeiner 2002) under conditions where the trees still had the physiological capacity to respond to forest thinning. As the results of forest restoration research are elucidated over time (see Sections 3.3 and 8.0), restoration techniques will be refined to better achieve restoration goals.

Table 4. Forest restoration methods targeting specific ecological objectives.

Ecological Objective	Methods to Achieve Objectives
Maintain or Stimulate Tree Growth/Encourage Tree Crown Development/Reduce Tree Competition	Thin trees to decrease competition
	Thin trees to increase light to individual tree canopies
	Create canopy gaps to increase light to tree canopies at gap edge
	Leave trees in canopy gaps to facilitate the growth of very large trees with large branch structure
Increase Species Diversity/Accelerate Understory Development	Thin trees to increase relative proportion of less frequent species
	Thin trees to increase light to forest floor
	Create canopy gaps
	Plant appropriate species not present or at low relative densities
Increase Structural Complexity and Spatial Heterogeneity/Increase Snags and Downed Wood	Thin trees to accelerate growth (create emergent trees, creating canopy roughness, potential snag/downed wood recruitment)
	Thin trees to variable densities to variably increase light to forest floor (increases tree, shrub, and herb regeneration and growth)
	Create canopy gaps
	Leave trees in gaps to facilitate development of large trees (faster height growth, creating canopy roughness)
	Create skips or leave areas
	Retain subdominant and understory trees during thinning
	Retain shrubs and herbs during thinning
	Retain existing snags and unique trees during thinning
	Retain existing downed wood during thinning
	Create snags
	Create downed wood
	Maintain all deciduous trees and relatively rare conifer trees
	Plant appropriate species not present or at low relative densities
	Apply treatments variably across the landscape to provide spatial heterogeneity and mosaics of habitat patches at the local forest scale
Improve Old-Growth Forest Habitat Connectivity	Restore forest areas on a scale likely to impact the habitat availability of targeted wildlife species at a population level
	Choose restoration sites based on landscape juxtaposition with existing old-growth forest, second-growth forest where restoration may occur, or other landscape prioritization metric (e.g., long-term linkage between basins)
Minimize Catastrophic Loss	Limit amount of downed wood created from thinning trees (increases hazard of fire, insect outbreaks, and disease)
	Target restoration techniques to specific forest characteristics
	Plan interventions acknowledging uncertainty with a sense of humility and conservatism
	Monitor impacts of restoration and implement adaptive management

Figure 4. Conceptual model of the effects of forest restoration programs in the CRMW on ecological processes.



3.3 Why Restore Second-Growth Forests?

A history of commercial forest management has severely degraded the ecological value of the forests in the Pacific Northwest. Approximately 84 percent of the forests in the CRMW are in early- to mid- successional stages, where much of the habitat complexity and functionality characteristic of late-successional forest is lacking (Hunter 2001, Muir et al. 2002). Consistent with the condition of watershed forests, there has been only one documented northern spotted owl nest in the CRMW in the last 15 years, along with one northern goshawk nest, and one sighting of a marbled murrelet. The theoretical carrying capacity of the CRMW with fully restored late-successional forest would be 14 pairs of spotted owls, 15 pairs of goshawks, and numerous murrelets. The forests of the CRMW are now being managed as an ecological reserve to provide habitat for wildlife species dependent on late-successional forest. Late-successional conditions, however, will take decades and even centuries to develop on their own from earlier successional stages (see Section 3.1). Applying the conservation measures committed to in the CRW-HCP, including ecological and restoration thinning and restoration planting, can shorten the time for these late-successional forest characteristics to develop and can provide increased ecological functionality in the near- to mid-term (Lindenmayer and Franklin 2002).

3.3.1 Benefits to Wildlife from Forest Restoration

With the primary long-term goals of forest restoration in the CRMW being accelerating the amount and connectivity of late-successional forest, the benefits to wildlife species dependent on old-growth forest are obvious. Restoration, however, can simultaneously provide increased ecological functionality and wildlife habitat in the near- to mid-term. Conventional commercial thinning (e.g., evenly thinning lower canopy trees), which is simpler than ecological thinning in its application, has been shown to benefit many wildlife species (Aubry et al. 1997). Amphibians (Aubry 1997, Aubry 2000), small mammals (Carey and Johnson 1995, West 1997, Wilson and Carey 2000, Hayes and Larson 2001, Suzuki and Hayes 2003), bats (Erickson 1997, Humes et al. 1999), and birds (Hagar et al. 1996, Manuwal and Pearson 1997, Haveri and Carey 2000, Muir et al. 2002) have all been shown to be more abundant in forests that were thinned, when compared to unthinned closed-canopy forests. Increased forage (shrubs and herbs) in thinned areas can also promote ungulate use (Hayes et al. 1997), and higher densities of prey (amphibians, small mammals, and birds) in thinned forests would be expected to support higher populations of small carnivores and raptors, although this has not yet been tested. Thinning affects different species differently, however, with abundance of some bird species decreasing in thinned areas (Hayes 2003).

While conventional thinning increases light to the forest floor and increases tree growth, it also reduces structural heterogeneity, species diversity, and biocomplexity, and can result in lower densities of snags and downed wood. In contrast, ecological thinning, which includes creating variable spacing between trees, leaving a range of tree sizes, creating gaps, leaving patches of dense forest, favoring uncommon species (including deciduous trees), and maintaining and creating downed wood and snags, increases heterogeneity and species diversity and will provide even greater benefit to wildlife species. Variable density thinning, one application of ecological thinning, resulted in increased plant species richness and herb cover compared with controls (Carey and Wilson 2001). There was a positive short-term affect on most small mammals, especially those associated with understory shrubs, herbaceous vegetation, and open canopy. While conventional thinning had apparent long-term (>10 years) negative affects on northern flying squirrels, the primary prey of the northern spotted owl in western Washington, variable density thinning resulted in short-term population reductions from which the squirrels subsequently recovered (Carey and Wilson 2001). The abundance of deciduous trees and shrubs is positively related to species richness, total abundance of birds, and the abundance bird species (Starkey and Hagar 2001, Muir et al. 2002). Large snags and downed wood are important habitat elements for cavity nesting species, bats, small mammals, and amphibians (Arnett 2004 pers. comm., Butts and McComb 2000, Johnson and O'Neill 2001, Maser et al. 1975). Ecological thinning projects, which will include large snag and downed wood retention and creation, will supplement these critical habitat elements in the near and mid-term while the forest is developing to a point where natural dead wood processes will provide these habitat elements. Several studies have recently been initiated in the Pacific Northwest to investigate the response of wildlife species to ecologically based thinning, and more data on which to base future management decisions will be forthcoming.

3.3.2 Risks of No Restoration

The primary risk of non-intervention in second-growth forests includes the possibility of a prolonged competitive exclusion successional stage that could include:

- tree crown reduction potentially leading to tree growth stagnation;
- increased tree stress leading to greater susceptibility to windthrow, disease, and insect infestation;
- homogenous forest conditions, supporting low biodiversity and providing poor wildlife habitat; and,
- longer time to develop habitat suitable for old-growth forest dependent wildlife.

Some forests in the competitive exclusion stage may approach stagnation, where little growth occurs for many decades, and the forest area is dominated by relatively small-diameter dense trees with sparse understory (Oliver and Larson 1996, Spies 1997). Competition in very dense forest areas can result in severe crown reduction, decreased root development, and increased height:diameter ratios, resulting in "spindly" trees that are tall but with small diameters and little root strength (Wonn and O'Hara 2001). If forest areas are left in this condition, trees can become so unstable that they often remain standing by mutually supporting each other (Groome 1988). This increases the risk of large areas of windthrow during storm events and decreases the ability of individual trees to respond to increased light when it does become available (Oliver and Larson 1996, Wonn and O'Hara 2001). This competitive exclusion stage of forest development is structurally simple (with little or no understory development and little structural complexity), has little plant diversity, and provides habitat for a limited number of wildlife species (Oliver et al. 1985, Erickson 1997, Manuwal 1997, West 1997).

Trees under the stress of competition for resources are more susceptible to diseases and insects (Oliver and Larson 1996) and the risk of windthrow (Edmonds et al. 2000). Excessive development of some forest diseases, such as laminated root rot (*Phellinus weirii*), and insect infestations, such as from the Douglas-fir beetle (*Dendroctonus pseudotsugae*), in some cases pose risks to forests in the competitive exclusion stage in the CRMW. Limiting the time spent in the competitive exclusion stage of forest succession and increasing forest complexity and diversity would decrease the risk of disease and insect infestation, and physical damage. It should be noted, however, that these biological and physical disturbance agents provide for natural processes within forest ecosystems, and moderate levels of these disturbances contribute to development of structural complexity and biodiversity. The CRW-HCP commits to encouraging small to mid-scale disturbances that have this effect, but must protect against disturbance levels that would pose a catastrophic risk to existing forests.

Forests in the competitive exclusion stage have relatively high natural mortality that may increase hazard of forest fire through the creation of fuels (e.g., dead trees). These forests also have dense and continuous forest canopies that can facilitate fire spread. Limiting the risk of catastrophic loss of forests through wildfire, by limiting the competitive exclusion stage and diversifying forest canopy condition, is one of the goals of the CRW-HCP. When the scale of activity of disease or insect agents becomes catastrophic in nature by, for example, leading to large-scale windthrow events, or when large-scale forest fires occur, the development of late-successional forests in the CRMW would be impeded and water quality would be jeopardized. Consequently, the CRW-HCP expressly commits to minimizing the chance of such catastrophic events.

3.3.3 Risks of Restoration

There is always some inherent uncertainty in ecosystem restoration, based on the complexity of natural systems and the limitations of our knowledge. Specifically, potential risks of forest ecosystem restoration, especially regarding ecological and restoration thinning, include:

- increased short-term risk of windthrow until tree root systems adjust to lower density;
- disturbance to existing understory vegetation and downed wood;
- damage to remaining trees;
- cutting of some existing snags to meet Washington state safety regulations;
- introduction of exotic species;
- removing too many trees so that there is an insufficient number in the future for recruitment as old-growth trees, large snags, or large downed wood;
- altered species composition from what might be found following natural disturbance and forest succession;
- forests not responding to management as expected; and,
- short-term increase in erosion potential which could compromise water quality.

Ecological thinning will reduce competition mortality, resulting in fewer small diameter snags for current and future use. Some types of thinning might provide an even light environment that could result in the understory being dominated by a single species (e.g., a “carpet” of western hemlock or salal), resulting in simplified, rather than complex, forest structure. More of the remaining large trees might die than expected.

Strategies for managing the risks of thinning include:

- reduce risk of windthrow by being conservative in number of trees and basal area removed, especially from areas on steeper slopes known to experience high winds, and, where needed, staging thinning in more than one entry to limit the degree of change in exposure to winds and to give remaining trees a chance to develop an adequate root system to resist windthrow;
- minimize ground disturbance by requiring the least destructive thinning methods (e.g., using helicopters or feller/bunchers);
- minimize disturbance to existing understory vegetation by requiring the maintenance of as many shrubs as possible, keeping equipment out of sensitive areas such as riparian zones, and creating "skips" around areas of high habitat value;
- protect and enhance downed wood by requiring the maintenance of all existing downed wood, creating more downed wood, and limiting bucking (cutting up) or moving large diameter wood;
- minimize damage to remaining trees by contract specifications and compliance monitoring;
- minimize cutting of snags for safety reasons (pursuant to Washington state law) by creating "skips" around known larger snags;
- design treatments to ensure an adequate number of trees are left to provide for both forest development and future mortality;
- leave an appropriate number of trees, especially large diameter trees;
- implement variable treatments across a project to increase landscape variability and as a hedge against treatment uncertainty;
- utilize treatments that will minimize the risk of simplifying forest structure;
- favor unusual species by thinning only the most prevalent species;
- increase forest structural diversity by creating various sizes of gaps and skips;
- monitor vegetation responses to the thinning treatments and gap creation to determine whether the treatments had the expected effects, and adaptively apply results; and,
- limit erosion potential and water quality impacts by minimizing ground disturbance.

3.4 Examples of Other Forest Restoration Projects and Programs

As stated many times in this plan, the science of forest restoration is a relatively young discipline in which no one has yet restored a functioning late-successional forest through active restoration management. There has been much recent interest in creating more heterogeneity and biodiversity in previously harvested forests, with numerous studies initiated in the past decade. There are several programs and research projects in the Pacific Northwest that have similar objectives to the upland forest restoration goals of the CRW-HCP, although many are designed to create habitat in a commercially working forest. A brief description of major projects and programs that could apply to restoration in the CRMW, including goals, methods, and initial results, is included in Appendix A. As more results become available, they will be used in benchmarking the CRMW upland forest restoration program (see Section 8.1).

3.5 Uncertainty and What We Do Not Know

Since forest restoration is largely an experimental science, there are many things that are not yet known about how to restore a sustainably functioning late-successional forest. This plan uses benchmarking (i.e., continuous review of similar programs), monitoring, targeted research, and adaptive management (see Section 8.0) to attempt to address these unknowns, such as:

- are restoration interventions more effective at specific forest ages?
- how does productivity (e.g., site class) affect the rate of success of restoration interventions?
- what was the range of initial conditions and trajectories of forest development after natural disturbance during the pre-settlement period in the different forest zones found in the CRMW?
- do different forest types (e.g., Pacific silver fir, western hemlock) respond differently to similar restoration interventions?
- what is the effect of different silvicultural prescriptions on forest development and biodiversity?
- how do restoration treatments influence the development of late-successional forest conditions?
- how does global climate change affect forest development and therefore restoration?
- what is the ecological role of canopy communities and can they be restored through intervention?
- what is the ecological role of soil communities and their effect on the process of succession, forest-level response to disturbance, and restoration?
- can the introduction of forest pathogens (e.g., disease, mistletoe) be used as a forest restoration tool?

3.5.1 Uncertainty and Desired Future Conditions

Old-growth forest conditions in the CRMW and beyond vary with different environmental conditions and the ecological history of an area. Taken with the inherent uncertainty of forest ecology, this variance in conditions makes establishing desired future forest conditions and restoration objectives, in terms of targets for specific forest characteristics, fraught with unpredictability. The main variables determining forest conditions, old-growth or otherwise, are soil productivity (e.g., site class), elevation (e.g., annual climatic cycles), site history, disturbance pattern, and long-term climate.

3.5.1.1 Soil Productivity

Soil productivity, defined in Section 3.1.3.2, affects the ability of vegetation to grow by providing nutrients, water, and a substrate to adhere to (Kimmins 1987). More productive and deeper soils in mountainous regions, like the CRMW, tend to be in valley bottoms or at lower elevations, often eroding from higher elevations. All other variables held constant, old-growth forest on more productive soils (e.g., lower site class) will tend to support larger trees (both in terms of diameter and height) at lower densities than less productive soils. Both overstory and understory vegetation will tend to be more diverse on more productive soils, and horizontal (e.g., variable densities) and vertical (e.g., canopy layers) structure will be more complex. Old-growth forest, therefore, can provide very different habitats depending on site productivity, which makes potential restoration targets very site specific.

3.5.1.2 Elevation (Forest Zone)

Elevation affects forest productivity by influencing climatic pattern (temperature and moisture conditions) and therefore growing season, decomposition rates, and other ecological processes. Elevation differences contributes to the varied species composition in forests, illustrated by the western hemlock zone below 3,000 feet above sea level and the Pacific silver fir zone above. Old-growth forests in the western hemlock zone tend to be dominated by western hemlock trees, with components of Douglas-fir, western redcedar, grand fir (*Abies grandis*), Sitka spruce (*Picea sitchensis*), and western white pine (Franklin and Dyrness 1988). Tree species composition in this zone is often a function of seed availability, shade tolerance, and water availability. Though truly climax forests are rare, very shade tolerant western hemlock will eventually (in 400-600 years) dominate over shade intolerant Douglas-fir (e.g., western hemlock can grow in a shady understory and are better able to replace overstory trees as they die over time). Douglas-fir trees remain dominant at dry sites. Pacific silver fir trees dominate the Pacific silver fir zone, with components of Douglas-fir, western hemlock, noble fir, western redcedar, and grand fir (Franklin and Dyrness 1988). Tree species composition in this zone is often a function of winter conditions, seed availability, and shade tolerance. While the largest trees in an old-growth forest in the Pacific silver fir zone will likely be Douglas-fir, their intolerance to shade allows western hemlock and Pacific silver fir to better establish in the understory. Unlike the western hemlock zone, however, snow accumulations mechanically limit western hemlock (e.g., they break under high snow loads), and Pacific silver fir eventually come to dominate. Deciduous trees are rare in old-growth forest in both zones, except in recently disturbed or specialized sites (e.g., riparian areas).

Old-growth forests in the Pacific silver fir zone tend to support higher trees per acre, higher volume given stand density, and generally smaller trees, both in terms of height and diameter, than old-growth trees in the western hemlock zone (Brockway et al. 1983, Splechtna 2001, Franklin 1982). It is difficult to assess whether this difference is due to the generally smaller stature of Pacific silver fir trees when compared to western hemlock and Douglas-fir, or rather to factors such as soil productivity in the higher elevations.

3.5.1.3 Site History

The old-growth forests of today likely originated naturally from major disturbance events such as wildfire, windthrow, flooding, and volcanic eruptions, which may or may not have left behind biological legacies (e.g., live trees, snags, and downed wood). The forests were also subject to periodic smaller scale disturbances (e.g., less intense wildfires, windthrow, insects, and disease) that were not stand replacement events, but affected the structure and function of the forest thereafter. Unlike these forests, the second-growth forests of today originated naturally or by replanting of selected species after clearcut timber harvesting, which did not leave many remnant large tree legacies. These forests grew in a landscape largely devoid of wildfire (except in the lower watershed), since active fire suppression usually accompanied commercial timber management and continues today in the CRMW. Given the difference in the old-growth and second-growth forest disturbance regimes and the resulting successional trajectories, there is uncertainty whether second-growth forests can, or even should, resemble current old-growth forests in the CRMW in terms of species composition, even with restoration interventions that mimic small scale disturbance.

3.5.1.4 Climate

Climate, exclusive of the variability attributable to elevation, plays a key role in the uncertainty of determining forest restoration objectives. The old-growth forests of today grew under different climatic conditions in the past 200-800 years than the second-growth forests we are attempting to restore to old-growth forest (Henderson and Brubaker 1986). Natural climatic oscillations, on a temporal scale of decades or centuries, regardless of their cause, affect how trees grow (e.g., temperature, precipitation, solar energy). It is unknown how future climatic conditions, which are likely to be significantly different than in the past, will affect forest growth, or if the specific characteristics of old-growth forest of today are an appropriate target for restoration of second-growth. Tree growth and the specific resilience of certain species is directly affected by climatic conditions.

3.5.1.5 Disturbance

Disturbance of forest ecosystem occurs at many spatial and temporal scales and is critically important in determining species composition, structural complexity, and biological diversity. Disturbance clearly occurs before the stand initiation successional stage (Oliver and Larson 1996), and various types of disturbance continue throughout the life of a forest. The process of competition among trees for light, nutrients and water is one type of disturbance that results in fairly uniform tree mortality. Disease caused by fungal pathogens and mortality due to insects (e.g. bark beetles) are type of small scale but ubiquitous disturbance that create gaps in the forest canopy and generate snags and down wood (Franklin et al. 2002). Physical disturbances such as windthrow and snow breakage can create canopy gaps, snags, down wood, and trees with unique features. Fire clearly regulates the successional process in forest ecosystems. In the CRMW, many of the old-growth forests regenerated following fire approximately 300 years ago (Henderson & Peter 1981). The fire return interval on the west side of the Cascades crest is in the range of 400 years (Agee 1993), so when a fire burns in the CRMW it will probably be a stand replacing disturbance event. The forest restoration strategies that will be employed in the CRMW are modeled after the smaller scale disturbance types (wind, physical damage, insects, and disease), as well as the process of competition, which ultimately reduces stand density over time.

3.5.1.6 Natural Variability

The four variables above, along with other variable environmental conditions that affect the growth of vegetation (e.g., aspect, microclimate, and proximity to seed sources), have direct impact on the natural variability of forest conditions, in old-growth or otherwise. Table 5 summarizes data taken from 19 permanent sample plots (PSPs) in old-growth forests in the CRMW. This data illustrates the natural variability in old-growth forests, and indicates that the density of trees in old-growth forests in the CRMW directly impacts tree size (e.g., lower densities have larger diameter trees). Site class also affects the dominant tree species, but the data do not account for the more productive forest areas (e.g., site class II or better) in the CRMW that occur in lower elevation second-growth forests. Western hemlock dominates the more productive areas (e.g., site class III) while Pacific silver fir dominates the less productive areas (e.g., site class V). Confounding forest zone designations, however, the highest elevation PSP (4,469 feet asl) is dominated by western hemlock while the lowest PSP (2,252 feet asl) is dominated by Pacific silver fir. There is no relationship between density, site class, and elevation, or diameter, site class, and elevation. The density of trees greater than 5 inches dbh ranges from 60 to 267 trees per acre. The largest tree on any plot was 68 inches dbh and occurred on site class IV soils at 4,199 feet asl. The smallest "large tree" on any plot was 29 inches dbh, occurring on site class III soils at 3,130 feet asl. "Large tree" is clearly a relative term, but is also hard to predict.

Table 5. Summary of old-growth forest data from the CRMW.

Site Class		**III**	**IV**	**V**	**Unknown**	**Overall**
# Plots		4	4	7	4	19
Elevation	Average	3,224	3,797	3,219	3,218	3,342
	Range	2,542-3,679	3,216-4,199	2,252-4,465	2,290-4,469	2,252-4,469
Dominant Tree Species		WH	SF or WH	SF	SF or WH	SF or WH
Tree Density (tpa)	Average	150	181	183	151	161
	Range	60-194	89-267	61-250	89-151	60-267
Ave dbh (")	Average	21.4	15.8	18.1	22.6	19.2
	Range	16.6-27.6	11.0-23.0	12.7-22.7	19.0-28.2	11.0-28.2
Max dbh (")	Average	38.3	53.9	34.7	44.1	41.5
	Range	29.0-47.8	41.3-68.0	29.1-47.4	35.9-51.3	29.0-68.0

WH = western hemlock, SF = Pacific silver fir

Given the uncertainties of the four main forest condition variables and the natural variability of tree densities and diameters in old-growth forests, it is difficult to construct the trajectories of second-growth forest, whether they are subject to restoration or not. Monitoring of the success of forest restoration in the CRMW, therefore, will concentrate on documenting measurable key forest attributes that are targeted by our restoration program, and compare them to similar control areas where no restoration activity is implemented (see Section 8.2). It is important to remember, however, that forests do not follow one path in successional development (Hunter 2001), so allowing for a variety of successional trajectories in the CRMW landscape is crucial. Those area where forest restoration strategies are implemented will experience a different successional pathway than the remaining areas where no intervention occurs.

4.0 UPLAND FOREST HABITAT IN THE CEDAR RIVER MUNICIPAL WATERSHED

The land use history in the CRMW over the past century has converted 71,500 acres of old-growth forest to earlier successional stages, now ranging in age from approximately 10 to 100 years old (Figure 5). Most of the forest disturbances are attributed to clearcut logging and associated road building and related human activity, although there were also several town sites and railroad logging camps scattered throughout the CRMW. In addition, wildfires were ignited by railroad trains and slash burning and spread through portions of the CRMW, primarily in the lower watershed. The second-growth forests resulting from these disturbances span the western hemlock, Pacific silver fir, and mountain hemlock (*Tsuga mertensiana*) forest zones (Franklin and Dyrness 1973, Henderson and Peter 1981). Remaining old-growth forests in the CRMW are found in these vegetation zones as well.

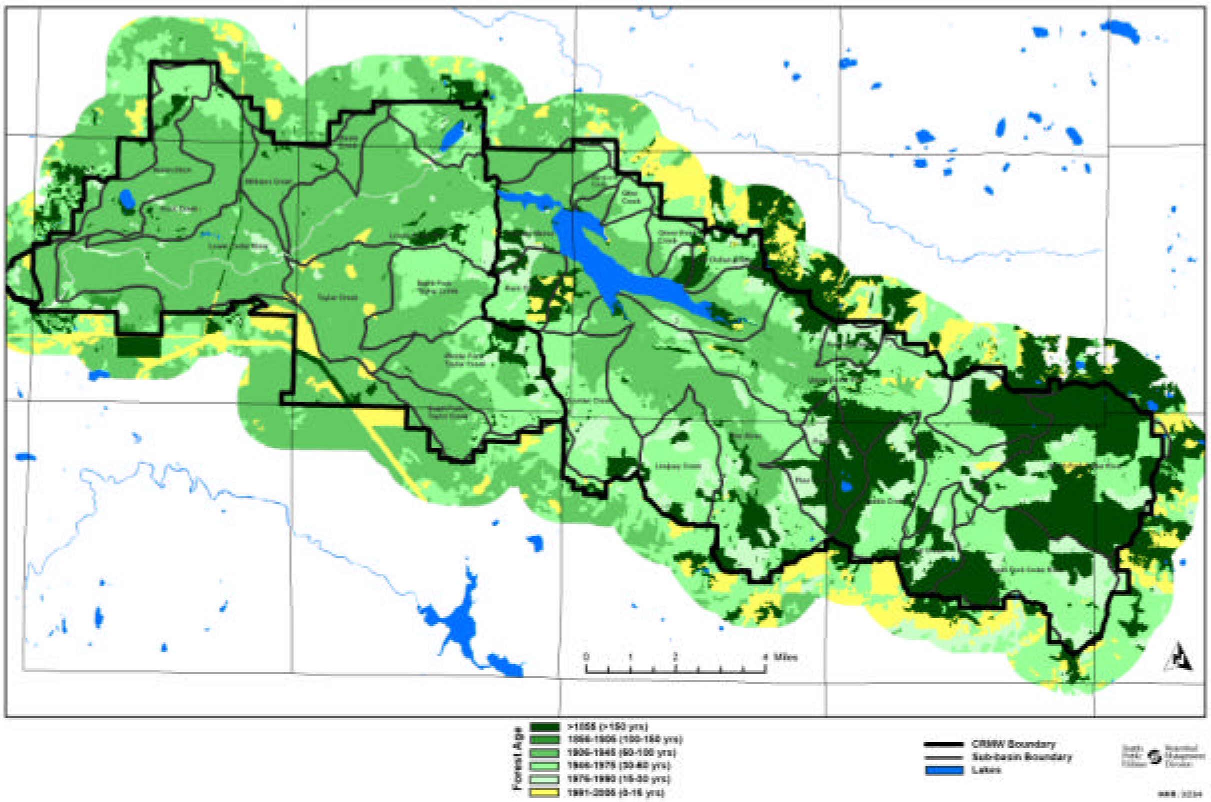
This section describes the extent of the forest (see Section 4.1) and the condition of those forests (see Section 4.2) as well as WMD staff can currently determine. Discussion then focuses on the primary processes that are presumed to be occurring in those forest types and upon which restoration treatments are targeted (see Section 4.3). Issues of scale, variability, and research questions are discussed.

4.1 Extent of Forests in the CRMW and Beyond

The term "*extent*" is used to describe the geographical context of the CRMW. Extent can be considered at a variety of landscape scales, with scale being defined in an ecological context. Considering extent at different scales illustrates the importance of the landscape concept to our restoration efforts.

In the broadest scale, the CRMW can be considered a relatively small sub-unit of the forests of the Pacific Northwest. In 1997, the United States Forest Service estimated that there was approximately 80,644 square miles of forestland in Washington and Oregon. In a regional context, the extent of the CRMW may be considered a sub-unit of a 17,300-square-mile ecoregion encompassing the western slope of the central and southern Cascade Mountain Range in Washington and Oregon. At a smaller scale, the CRMW may be defined as a 141.5-square-mile administrative unit owned by the City of Seattle and bounded by multiple administrative units comprising private, state, and federal ownership, or by the definition of a hydrographic boundary above the Landsburg Diversion Dam. Reducing our scale further we may consider the CRMW as a set of eight to 27 hydrographic basins or sub-basins, again depending on scale, each of which comprises a set of habitat patches. Each landscape context has a role in determining how restoration activities are planned and implemented. The regional context is important to restoration activities in that our ecological goals are established in part by a consideration of the needs of species that use an area larger than the CRMW. The administrative or hydrographic boundary context constrains our efforts to a more localized area but maintains the concept that we are dealing with the sum of many parts while appreciating that our actions will influence, and are influenced by, our neighbors. The consideration of hydrographic sub-basins and the patches within them is relevant to the specific activity of prioritization of upland forest restoration activity (see Section 5.0). Consideration of extent at a small scale or over limited geographical areas is one component of the criteria established for selection of sites for upland forest restoration (also see Section 5.0). At this level we are concerned with small geographical areas within the CRMW. Typically, we are evaluating specific habitat patches within the CRMW as candidates for restoration activity.

Figure 5. Forest ages in the CRMW



Patches of forest habitat can be spatially described by their location, area, shape, and juxtaposition with other patches. Location can be defined by geospatial variables such as latitude, longitude, elevation, and hillside placement. Area and shape help to define the amount of core area habitat, which is generally not subject to edge effects associated with boundaries (Chen et al. 1995). The juxtaposition of forest habitat patches is a key variable in the connectivity of habitat for specific wildlife species. Each of these variables is addressed in the restoration project site selection and prioritization section of this plan (Section 5.0). A list of wildlife species that potentially occur in the CRMW and their associated habitats is included in Appendix B.

4.2 Condition of Forests in the CRMW

"*Condition*" is defined as a measure or series of measures that qualitatively or quantitatively characterize the habitat components of the CRMW with respect to what might occur under natural conditions or what might be possible to achieve to emulate a more natural trajectory or final set of conditions in the future. This broad definition of condition is used in order to encompass the physical, compositional, and structural properties of habitat within the CRMW to provide a basis for determining, intimately, where restoration activities would be appropriate. In addition to using condition to assess habitat, we may use a portion of these variables as indicators of ecological function and ecological processes occurring within the CRMW (see section 4.3).

As was the case for extent, there is a need to acknowledge that in some cases condition may be considered at different scales. This is particularly relevant when strategizing to collect observations and measurements. In this context we are concerned with the distribution and density of observations within a given geographical area. Thus we may use a widely spaced series of measurements to capture condition over the entire CRMW. In contrast we may use a very closely spaced series of measurements within a limited area. It is important to acknowledge that data used to describe upland forest condition as a driver for the process of site selection and prioritization for restoration will be different from those required to design specific prescriptions for restoration interventions at a given site (see Section 5.0).

In some cases the term “condition” has a comparative context in that decisions to undertake restoration activities are dependent upon an understanding of anticipated outcomes. Thus we have established as part of the process for determining the success of our interventions the concept of comparing conditions in upland forest with trajectories of forest development that may be derived from the scientific literature, compilation of data acquired outside the CRMW, or by modeling of forest development.

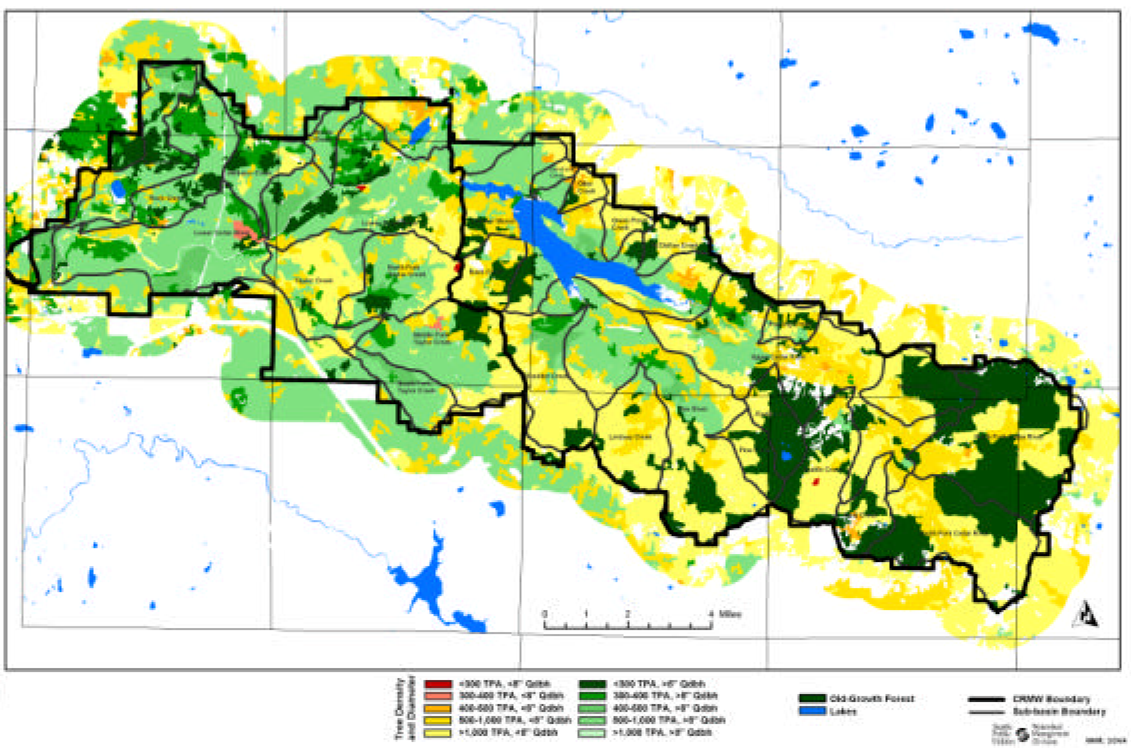
Estimates of the current condition of the forests in the CRMW are based on existing data and are subject to change as new datasets become available (see Section 6.0). Figure 5 illustrates the ages of forests in the CRMW, while Table 6 summarizes the forest condition in CRMW by age and elevation. There is a correlation between forest age after clearcut harvest and both tree density and tree size. Younger forests tend to be have greater tree density and smaller tree size, although other environmental factors also have a large influence on forest characteristics. Though we currently have a map of tree density and diameter (Figure 6), confidence in its accuracy is low (see Section 6.2). Specific environmental conditions (e.g., aspect, site class) also affect the boundaries between forest zones, but the elevation classes shown in Table 6 generally represent the western hemlock zone (<3,000 feet), the Pacific silver fir zone (3,000 to 4,500 feet), and the mountain hemlock zone (>4,500 feet). Forest restoration projects are not currently planned for the mountain hemlock zone, because little timber harvest has occurred in that zone.

Given the site selection and prioritization framework (Section 5.0 and Appendix C) and the essential criteria for determining priority areas where forest restoration activities should be implemented, additional data are needed to describe the condition of second growth forests n the CRMW. A reliable map of forest age is currently available, but maps and datasets describing other criteria are also needed. Efforts are currently underway to acquire better data to select and prioritize restoration sites using the criteria specified in Section 5.0 and Appendix C.

Table 6. Estimated acres of forest in the CRMW by age and elevation (based on CRW-HCP Table 4.2-7).

Forest Age	Elevation <3,000'	Elevation 3,000-4,500'	Elevation >4,500'	Total
0-29	5,400	9,397	813	15,610
30-79	45,655	8,785	151	54,591
80-119	1,074	0	0	1,074
120-189	91	0	0	91
>190	2,565	9,217	2,107	13,889
Unknown	150	60	12	222
Total	54,935	27,459	3,083	85,477

Figure 6. Tree density and diameters in forests in the CRMW



For ecological thinning, the most important criterion is relative density (a combination of stem density and diameter at breast height). This information will be acquired through a combination of field sampling and remote sensing. Other data are also needed to prioritize ecological thinning areas, and these data will primarily come from field sampling. For restoration thinning, essential criteria include stem density and diameter. This information will also be acquired through field sampling and remote sensing. Other data, such as species composition, will be acquired through field sampling. For upland restoration planting, information is needed regarding plant diversity in second growth forests, in particular the diversity of mosses and lichens. The distribution of western hemlock dwarf mistletoe is also needed, because this parasitic plant greatly affects branch structure and habitat complexity in late-successional forests. If the distribution of these dispersal limited species is lower than expected in the CRMW, efforts will be made to plant these elements of diversity in second growth forests under the forest restoration programs. The stepwise application of these criteria is described more fully in Section 5.0.

4.3 Ecological Processes in Forests in the CRMW

As the preponderance of second-growth forest in the CRMW is in or near the competitive exclusion successional stage, based on forest age, tree density, and tree diameter, and is fairly limited in structural diversity and habitat value, the primary ecological process that Upland Forest Restoration will attempt to address is forest succession. Within the interventions targeted to accelerate forest succession will be efforts that focus on increasing habitat value, forest ecosystem complexity, and biological diversity. Specific indicators of successional development will include those structural conditions and associated processes identified in Tables 1, 2, and 4 and Figures 3 and 4 (Section 3.0). Most notably, the structural features (or lack thereof) of large trees, diverse species, continuous canopy layers, snags, downed wood, spatial heterogeneity, and understory vegetation will indicate where intervention may or may not be desired in a forest area. The presence or absence of these structural attributes will point to the ecological processes that are occurring and those that need to occur in a particular forest in order to achieve desired habitat characteristics and late-successional conditions. Silvicultural interventions will be prescribed in those high priority sites lacking these structures and processes in an effort to affect the successional processes, and thereby the structural conditions and ecological functions.

5.0 FRAMEWORK FOR PROJECT SITE SELECTION AND PRIORITIZATION

The cost of implementing upland forest restoration projects, both in terms of time and money, in all areas that would likely benefit outstrips the resources available for such projects. In order to efficiently select and prioritize upland forest restoration project sites, a set of forest characteristic criteria must be established and prioritized to guide restoration efforts. While we ultimately want to affect the ecological processes that are associated with the development and functioning of late-successional forest ecosystems, the processes are difficult to measure as specific criteria. Therefore, in many cases, structural conditions serve as surrogate criteria for the processes in which we are interested. This section addresses these criteria for each of the three program types, and provides scales of prioritization to help simplify the effort.

5.1 Conceptual Framework for Forest Restoration Project Site Selection and Prioritization

Upland forest restoration will occur in second-growth forest areas. No restoration interventions will be implemented in old-growth forest ecosystems, as these are protected by the CRW-HCP and will provide a reference for restoration activities. Similarly, second-growth forests that have well-developed structural complexity and species diversity will not be subject to restoration activities, as they are already meeting the ecological needs as outlined in the CRW-HCP. These areas will be used for comparative purposes, however, and may serve as guides to our restoration activities in less structurally complex and adjacent second-growth areas.

The conceptual model for applying the site selection and prioritization criteria to identify upland forest restoration project areas is based on a systematic progressive filtering method. Initially, "coarse-filter' site selection criteria will be applied to landscape level forest attribute data to identify forest areas that would likely benefit from a specific restoration activity (ecological thinning, restoration thinning, or upland planting). This filtering effort will largely be a geographic information system (GIS) exercise utilizing the best available landscape-level data (see Section 6.0). Primary and secondary levels of criteria are used, where appropriate, to prioritize areas that might respond to forest restoration treatments to a greater degree. Secondly, areas identified with the coarse-filter will be prioritized using the most appropriate landscape-level prioritization criteria. It is anticipated that prioritization standards will change over time as restoration objectives are achieved at different landscape scales. Informed professional opinion will be used in the cases where prioritization criteria contradict one another. Thirdly, "fine-filter" site selection criteria will be applied to prioritized forested areas that would likely benefit from restoration. Fine-filter site selection criteria are data that are not readily collected at a landscape scale, but at a forest stand scale utilizing field-based forest sampling techniques. And finally, project sites will be chosen from areas emerging from the fine-filter utilizing the stand-level prioritization criteria. This progressive filtering approach will provide a systematic cost-effective and defensible method of utilizing the site selection and prioritization criteria by ensuring that the information that is most expensive to obtain (e.g., field data) will be collected on the smallest number of acres.

Site selection and prioritization criteria for ecological thinning, restoration thinning, and upland planting are listed separately in Tables 7, 8, and 9, respectively. A more detailed description of each criterion is included in Appendix C.

Table 7. Site selection and prioritization criteria for ecological thinning projects in the CRMW.

Project Type	Site Selection/ Prioritization	Filter/ Scale	Characteristic	Primary	Secondary
Ecological Thinning	Site Selection	Coarse-Filter	Tree Density	400-1000 trees/acre	300-400 trees/acre
			Tree Diameter	>8" dbh	-
			Stand Density Index/Relative Density	>290 SDI, >50 RD	-
			Tree Age	30-60yrs	60-100 yrs
			Canopy Closure	>90%	70-90%
			Site Class	IV	II, III, V
			Slope	<35%	35-75%
			Aspect	SW	Other
			Elevation	<4,500' asl	-
		Fine-Filter	Tree Diameter Growth	>15 rings/inch	7-15 rings/inch
			Live Crown Ratio	>40%	30-40%
			Canopy Layering	1 layer	-
			Tree Species Diversity (abundance)	1 species >80%	1 species 45-80%
			Understory Development (ground cover)	<10%	10-40%
			Understory Species Diversity (abundance)	1 species >65%	1 species 35-65%
			Snags	<2/acre, >15" dbh & >20' tall	-
			Downed Wood	<500 ft^3/acre, >6" diameter	-
			Horizontal Structural Diversity	Homogeneous	-
	Prioritization	Stand	Water Quality Impacts	-	-
			Stand Size	-	-
			Plant Species Diversity	-	-
			Structural Complexity	-	-
			Specific Wildlife Benefit	-	-
			Riparian Habitat	-	-
			Road Access	-	-
			Seasonal Limitations	-	-
			Thinning Method	-	-
			Likelihood of Re-entry	-	-
			Monitoring Efficiency	-	-
			Cultural Resources	-	-
			Affordability	-	-
		Landscape	Proximity to Late-Successional Habitat (connectivity)	-	-
			Quality of Late-Successional Habitat	-	-
			Proximity to CRMW Boundary	-	-
			Sub-Basin Planning	-	-
			Restoration Patch Size & Juxtaposition	-	-
			Upper/Lower CRMW Connectivity	-	-
			Proximity to Other Ecological Thinning Sites	-	-
			Temporal Considerations	-	-
			Coordination with Other Restoration Projects	-	-

"-" = not applicable

Table 8. Site selection and prioritization criteria for restoration thinning projects in the CRMW.

Project Type	Site Selection/ Prioritization	Filter/ Scale	Characteristic	Primary	Secondary
Restoration Thinning	Site Selection	Coarse-Filter	Tree Density	>1,000 trees/acre	30-40 yrs
			Tree Diameter	<8" dbh	500-1,000 trees/acre
			Tree Age	15-30 yrs	30-40 yrs
			Canopy Closure	>80%	60-80%
			Slope	<35%	>35%
			Aspect	SW	Other
			Elevation	<4,500' asl	-
		Fine-Filter	Tree Species Diversity	1 species >80%	1 species 45-80%
	Prioritization	Stand	Water Quality Impacts	-	-
			Stand Size	-	-
			Road Access	-	-
			Tree Diameter	-	-
			Plant Species Diversity (abundance)	-	-
			Affordability	-	-
			Riparian Habitat	-	-
			Thinning Method	-	-
			Likelihood of Re-entry	-	-
			Monitoring Efficiency	-	-
		Landscape	Proximity to Late-Successional Habitat (connectivity)	-	-
			Quality of Late-Successional Habitat	-	-
			Proximity to CRMW Boundary	-	-
			Sub-Basin Planning	-	-
			Upper/Lower CRMW Connectivity	-	-
			Proximity to Other Restoration Thinning Sites	-	-
			Temporal Considerations	-	-
			Coordination with Other Restoration Projects	-	-

"-" = not applicable

Table 9. Site selection and prioritization criteria for upland planting projects in the CRMW.

Project Type	Site Selection/ Prioritization	Filter/ Scale	Characteristic	Primary	Secondary
Upland Restoration Planting	Site Selection	Improving Tree Stocking Levels	Tree Age	<15 yrs	-
			Tree Stocking	<190 trees/acre	-
			Tree Species Diversity (abundance)	1 species >80%	-
			Understory Species Diversity (abundance)	1 species >65%	-
			Canopy Layering	1 layer	-
			Planting History	Natural Regen	Planted
			Site Class	III-IV	-
			Aspect	SW	Other
			Elevation	<4,500' asl	-
		Improving Tree Species Diversity at Other Restoration Sites		-	-
		Improving Diversity of Other Plant Species		**	-
	Prioritization	Stand	Water Quality Impacts	-	-
			Stand Size	-	-
			Plant Species Diversity	**	-
			Structural Complexity	**	-
			Specific Wildlife Benefit	-	-
			Road Access	-	-
			Likelihood of Re-entry	-	-
			Monitoring Efficiency	-	-
			Affordability	**	-
		Landscape	Proximity to Late-Successional Habitat	-	-
			Sub-Basin Planning	-	-
			Upper/Lower CRMW Connectivity	-	-
			Proximity to Other Upland Planting Sites	-	-
			Temporal Considerations	-	-
			Coordination with Other Restoration Projects	-	-

"-" = not applicable
"**" = assessment needed

6.0 DATA AND ANALYTICAL TOOLS

The data required to drive the upland forest restoration program includes information to both select and prioritize restoration sites and to monitor our progress in achieving the forest management goals as dictated by the CRW-HCP. This section outlines the data requirements of the program (Section 6.1), the data currently on-hand at the WMD (Section 6.2), and additional data that is required or is currently under development (Section 6.3). We also address the tools that are available to develop and analyze these data (Section 6.4).

6.1 Data Requirements

Forest attribute data will be required for each of the site selection and prioritization criteria outlined in Section 5.0 and described in detail in Appendix C. Coarse-filter site selection data and landscape-level prioritization data are generally developed over the landscape from existing sources, or from remotely sensed data verified by field reconnaissance, and can be utilized and analyzed using GIS and other tools (see Section 6.4). Fine-filter site selection data and stand-level prioritization data are generally developed from field sampling forays, and analyzed using various tools including GIS.

Data required for monitoring the progress in achieving the forest management goals of the CRW-HCP are generally consistent with those required to select and prioritize forest restoration sites. A more detailed discussion of monitoring data is included in the Monitoring Strategic Plan (Nickelson et al. 2003) and Section 8.0.

6.2 Review of Data On-Hand and Under Development

A large amount of forest inventory, mapping, and research has been done in the CRMW over many years. The detail and coverage of the various types of information, as well as the quality of documentation, varies greatly. Efforts are currently underway to both assess the status of currently available information and complete information gaps and to upgrade the data storage and retrieval processes (Watershed Characterization ID Team). Our intent is to develop a strategy that will leverage existing data with new data acquisitions in order to provide a defensible and transparent decision-making process for planning upland forest restoration activities, as well as support essential monitoring.

A complete description of on-hand data is available in Munro et al. (2003). A review of the 12 datasets currently on-hand at the WMD that are most relevant to upland forest restoration is included in Appendix D. Other image datasets available include 15 sets of aerial photographs (both black and white and color) dating back to 1956, unclassified 1992 LANDSAT satellite imagery (7 bands, 30m pixels), and unclassified 2000 IKONOS satellite imagery (3 or 4 bands, 4m and 1m pixels).

Though the on-hand datasets provide a basis from which to select and prioritize near-term upland restoration projects (see Section 7.0), their documented inaccuracies compromise their use in confidently selecting and prioritizing upland forest restoration sites over the long-term. Therefore, significant effort is being placed on developing new datasets that provide a more confident assessment of forest attributes across the CRMW. Basically, the data development format for coarse-filter site selection and landscape prioritization includes the classification of remotely sensed image data collected across the CRMW landscape using ground-based sampling procedures at geographically referenced points for verification of image data. Data for forest characteristics that are not appropriately generated from this method, and are used for fine-filter site selection and stand prioritization, are collected using a modified forest inventory in areas that have a high potential to benefit from restoration activities.

Currently, there are four datasets (two remote sensing datasets and two field sampling datasets) currently under development at the WMD that should address most of the uncertainties associated with on-hand data. They are described in Appendix D. More information on these datasets can be obtained from the Watershed Characterization and Monitoring ID Teams.

6.3 Analytical Tools

Currently, WMD staff has several tools to analyze forest attribute data. These are described below.

6.3.1 Image Analysis Tools

Tools available in the analysis of image data include ENVI (*Environment for Visualizing Images*) software, ArcMap (and associated modules), and stereoscopes. ENVI (http://www.rsinc.com/envi/index.cfm) provides a basis for image data processing (e.g., MASTER and LIDAR data) and the classification of forest attributes. ArcMap (http://www.rsinc.com/envi/index.cfm) is a tool for digital map analysis, and stereoscopes provide for manual analysis of aerial photos.

6.3.2 Tree Growth Models

Tree growth models are a valuable forest management tool in that they predict tree growth through time based on a "library" of data for trees grown under similar environmental conditions (e.g., latitude, climate, elevation, aspect). Growth models have limited value in predicting absolute estimates of forest growth, however, because of many levels of uncertainty that are difficult to quantify. The strength of growth models lies in quantifying the relative difference between various management scenarios through time.

Two tree growth models are currently available and appropriate for modeling the growth of trees in the CRMW. The Forest Vegetation Simulator (FVS), developed and supported as freeware by the USDA Forest Service (http://www.fs.fed.us/fmsc/fvs/index.php), requires input tree data consistent with that collected by PSPs and forest inventories, and outputs estimates of tree growth, mortality, snags and downed wood generation over time. The Forest Projection and Planning System (FPS), developed by Forest Biometrics (http://www.forestbiometrics.com), requires similar input data and outputs estimates of tree growth over time. Both growth models allow for simulating various forest management scenarios and feed the Stand Visualization System (SVS), a tool developed at the University of Washington (http://forsys.cfr.washington.edu/svs.html) to graphically represent forest stand data. Advantages of FVS include free national software support, ongoing upgrades, extensions for analysis of other forest processes (e.g., insect and disease, fire and fuels), and a condition-based management planner (e.g., simulate specified management action when forest conditions reach a specified state). Advantages of FPS include the ability to grow trees specifically under density dependence (this requires input of x and y coordinates for trees, which is data not typically collected during cruise inventories). Recent work has shown that the forest inventory dataset that is nested within the FPS model has many errors. To correct these errors and continue to use FPS would require a significant effort. Given the issues stated above, FVS is the preferred model to use to support forest restoration planning.

6.3.3 Landscape Models

The Landscape Management System (LMS) is a model designed to assist in landscape level analysis and planning of forest ecosystems by automating the tasks of stand projection, graphical and tabular summarization, stand visualization, and landscape visualization (http://lms.cfr.washington.edu). Compatible with data output from FVS, LMS is a freeware analysis tool that allows the simulation of forest growth and management over large areas and provides a basis for landscape-level planning of forest management. This tool would help to evaluate landscape impacts of forest restoration.

6.3.4 Wildlife Habitat Models

The Program to Assist Tracking Critical Habitat (PATCH) is a spatially explicit, individual-based, life history simulator designed to project populations of territorial terrestrial vertebrate species through time (http://www.epa.gov/wed/pages/models/patch/patchmain.htm). Input data requirements for PATCH include landscape level maps of habitat availability, specifications for habitat use (habitat affinity and territory size), vital rates (survival and reproduction), and parameters for species' movement behavior. PATCH outputs data in two general categories: pattern-based metrics and demographic analyses. Pattern-based outputs include patch-by-patch descriptions of landscapes, assessments of the number, quality, and spatial orientation of breeding sites, and map-based estimates of the occupancy rate and the source-sink behavior of breeding habitat. PATCH's principal demographic outputs include several measures of population size as a function of time, realized survival and fecundity rates (rates that reflect the limitations on a population imposed by habitat quality and landscape pattern), and assessments of the occupancy rate and source-sink behavior of the breeding sites present in a landscape.

PATCH, which is also freeware, can be used to assess the connectivity of habitat for late-successional forest dependent species (Richards et al. 2002) and help prioritize upland restoration projects locations. A preliminary assessment of the connectivity of late-successional forest habitat, using PATCH and existing forest attribute data, has been completed. The assessment ranks the potential habitat connectivity value in areas that will likely benefit from ecological thinning, providing a basis for prioritization. A final analysis will be conducted using data currently under development.

7.0 NEAR-TERM FOREST RESTORATION PROJECT SITES

Until data are developed to provide a complete site selection and prioritization of upland forest restoration sites (see Section 5.0), the data currently on-hand and WMD institutional knowledge have been utilized to identify near-term forest restoration project sites (spanning approximately five years). These near-term project sites are described below for ecological thinning, restoration thinning, and upland planting. In general, these project sites meet the detailed selection criteria and the prioritization criteria that are a priority at this point in the CRW-HCP implementation.

While the UFRIDT recognizes there are many areas that may require forest restoration in the CRMW, the near-term areas identified below satisfy the basic elements of this UFRSP and will not limit future restoration efforts developed on a more thorough review of existing forest conditions. These areas will be considered for restoration pending the finalization of the application of site selection and prioritization criteria to data currently under development (see Section 6.3).

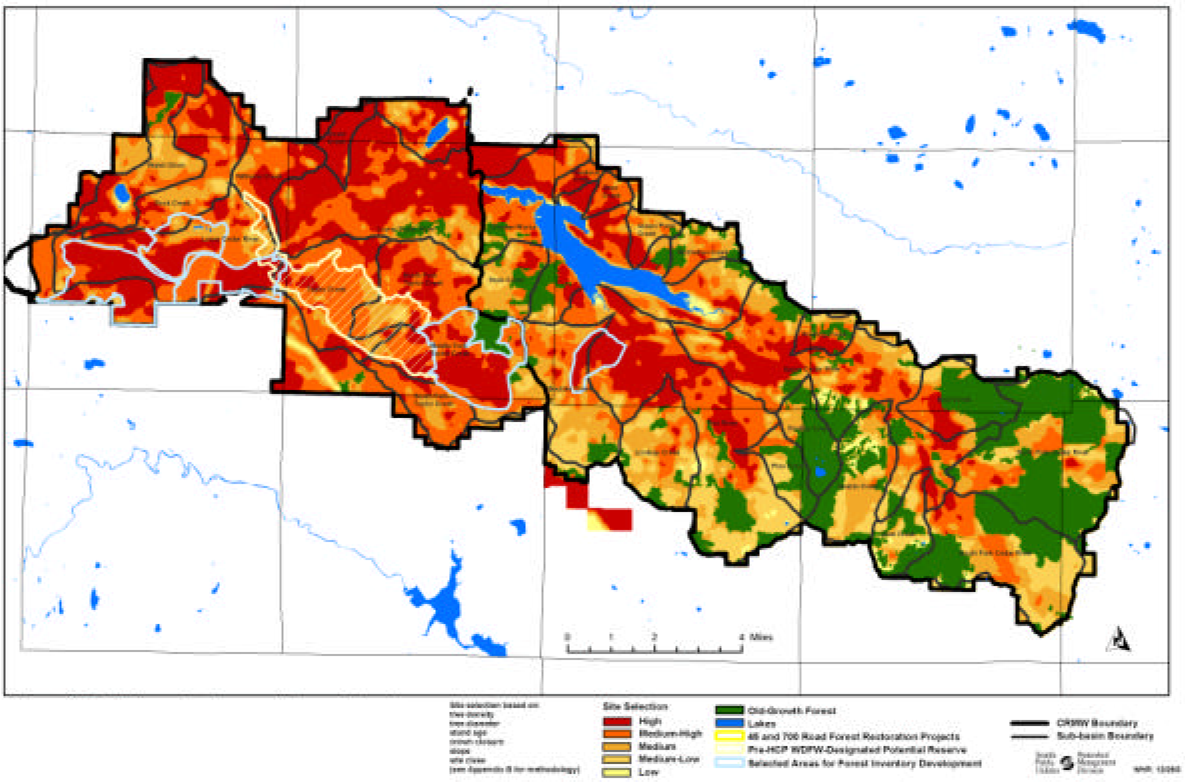
7.1 Near-Term Ecological Thinning Projects

Two ecological thinning project locations were selected prior to the implementation of the site selection and prioritization methodology outlined in this plan. The 45 Road Forest Habitat Restoration Unit was selected as the first ecological thinning project under the CRW-HCP because thinning would likely facilitate old-growth forest conditions in the project area, the unit is outside the hydrographic boundary of the watershed which limits any potential impacts to water quality, and because of adjacency to a county road which provides transparency in the application of our management. The management plan for this restoration project was completed in April 2003, and implementation commenced in the fall of 2003. The project was completed in early 2004, with ongoing monitoring. The 700 Road Forest Habitat Restoration Project was also selected because it will likely facilitate old-growth forest conditions in the project area, but also because of its juxtaposition in the Rex River sub-basin and potential to provide habitat connectivity with the old-growth forest in that sub-basin and beyond. The draft management plan for this project was completed in the spring of 2004, with implementation planned for the spring of 2005. Both the 45 Road and the 700 Road Forest Habitat Restoration Projects are representative of forest conditions in the lower and upper CRMW, respectively. Monitoring these two ecological thinning projects will indicate potential for future success in similar forests throughout the watershed.

All other near-term ecological thinning projects were identified using the site selection and prioritization methodology outlined in this plan and applied to on-hand data or data developed in the near-term (e.g., forest inventory over limited areas). Coarse-filter criteria (Table 7) were applied to on-hand data developed from TBS, MBG, DEM, and SCS datasets (see Appendix D). Low confidence in the TBS data, however, limits its use for selecting potential restoration sites in the long-term. Figure 7 illustrates the resulting priority areas based on a coarse-filter site selection spatial model that includes tree density, tree diameter, stand age, crown closure, site class, and slope. The methods used to create the model are included in Appendix E. Other project sites that would potentially benefit from ecological thinning in the CRMW, but which were not identified by this method due to the limitations of available data, will be identified as data sources are upgraded through time.

Based on prioritization of potential ecological thinning sites that increase the late-successional forest habitat connectivity between the upper and lower CRMW, five areas were identified that provide connectivity between the old-growth forest and the 700 Road Forest Habitat Restoration Project in the upper CRMW, a potential reserve of nicely developing second-growth forest in the Taylor Creek basin identified by Washington Department of Fish and Wildlife (WDFW) personnel during the CRW-HCP development process, and the 45 Road Forest Habitat Restoration Project in the lower CRMW (Figure 7). These areas include three adjacent areas in the Lower Cedar River sub-basin, one area in the Middle Fork Taylor Creek sub-basin, and one area in the Rex River.

Figure 7. Spatial model of coarse filter ecological thinning site selection criteria and potential near-term ecological thinning project locations in the CRMW.



The acquisition of fine-filter data is currently being organized in each of these potential project areas to further select restoration sites. Forest inventory data will be collected in the three areas in the Lower Cedar River sub-basin during the winter of 2003-04, while an inventory for the other two areas will likely occur in the spring and summer of 2004. All of these proposed areas offer multiple ecological thinning project possibilities as least as large as the HCP target of 62 acres. Each area could support a multi-year project depending on the configuration of the projects themselves. The areas offer flexibility and opportunity in project design and multiple opportunities for applying various restoration concepts by themselves or in concert with other restoration projects. Actual project sites, which may be portions of the identified areas, will be identified following a comparative analysis of the forest inventory data. Areas that have forest attributes that will not likely benefit ecologically from thinning will be excluded from thinning projects, and areas will be selected for thinning that will likely benefit most.

The coarse-filter of data also identified additional areas near and adjacent to the Bonneville Power Authority (BPA) right-of way that may benefit from ecological thinning (e.g., 50.3-road area in the Lower Cedar River sub-basin (see below), Brew Hill area in the Rock Creek sub-basin). Restoration of these areas may be prioritized due to the compensation fund established as mitigation for expansion of the right-of-way in 2003.

7.1.1 Lower Cedar River Sub-Basin
The three potential ecological thinning areas identified in the Lower Cedar River sub-basin represent a strong beginning to enhancing the connectivity of maturing and old-growth forest within the lower CRMW. Identified by roads through each area, the 10.5, 50.3, and 58-road areas offer similar forest conditions as were found in the 45 Road Forest Restoration Project area. The 10.5-road area encompasses roughly 1,100 acres north of the Cedar River including the Fourteen Lakes riparian areas. The 50.3-road area is roughly 1,100 acres south of the Cedar River and on either side of the BPA right-of-way. The 58-road area has approximately 2,100 acres south of the Cedar River and adjacent to the Thompson Research Station.

7.1.2 Middle Fork Taylor Creek Sub-Basin
The potential ecological thinning area identified in the Middle Fork Taylor sub-basin is almost 2,100 acres in size and incorporates most of the upper sub-basin and surrounds approximately 500 acres of old-growth forest. Forests in this sub-basin provide vital habitat connectivity between the old-growth forests remaining in the upper CRMW with the maturing forest in the lower CRMW.

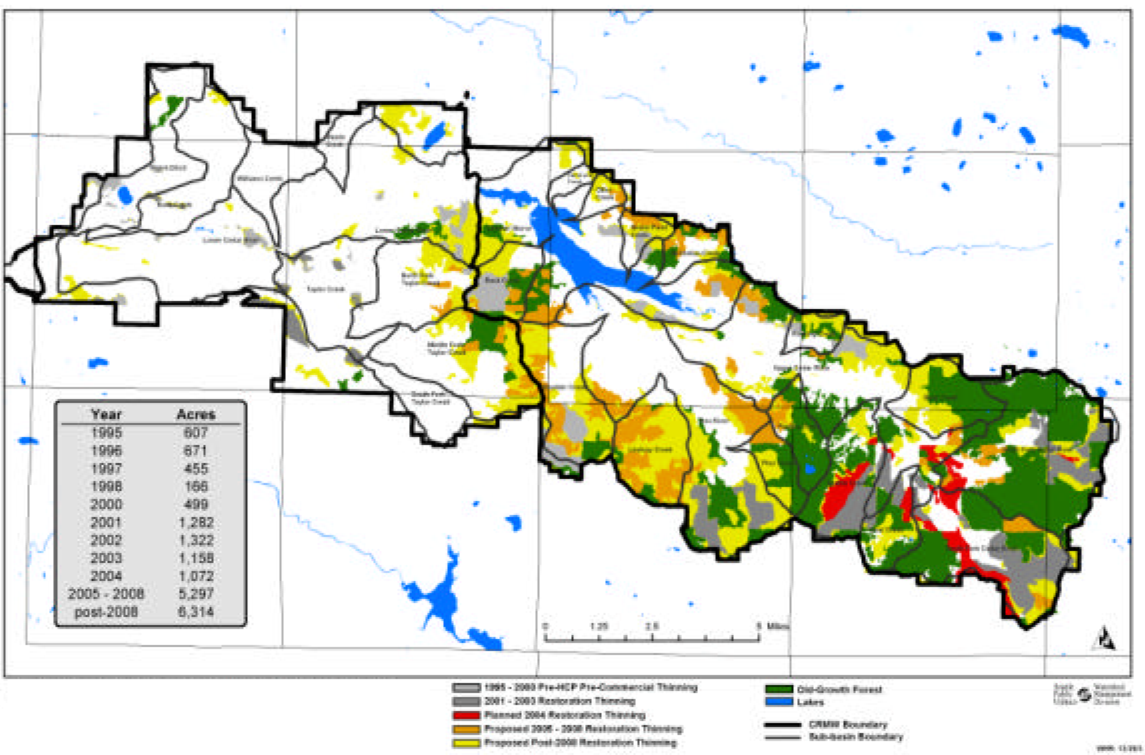
7.1.3 Rex River Sub-Basin
The 600-acre area identified in the Rex River sub-basin as a potential ecological thinning project is near the 700 Road Forest Habitat Restoration Project. Located along the 200-road system, forests in this area are typically dense with depauperate understory.

7.2 Near-Term Restoration Thinning Projects
Prior to the adoption of the CRW-HCP, roughly 1,900 acres of forest in the CRMW was pre-commercially thinned from 1995 to 1999 (Figure 8). Pre-commercial thinning is analogous to restoration thinning, in that the objective is to maintain tree growth rates in relatively young forest areas through limiting inter-tree competition for resources. In the first four years of implementing the CRW-HCP (2000 to 2003), approximately 4,260 acres of forest was restoration thinned. An additional 640 acres are planned to be restoration thinned in 2004. Details of treatment prescriptions can be found in the annual restoration thinning plans.

Figure 8 identifies areas in the CRMW that would currently most benefit from restoration thinning for the next five years based on the overlap of coarse-filter site selection criteria discussed above and available spatial data. There are other potential sites in the CRMW that would also benefit from restoration thinning which were not identified by this method due to data limitations. These areas will be identified through field reconnaissance and upgrading of data sources through time (see Section 6.3). Forest where restoration thinning would be an appropriate restoration treatment after the 15-year HCP period would be the result of an unanticipated future catastrophic event (e.g., windthrow, fire), which will have to managed outside of this plan.

According to the TBS-associated data, there is approximately an additional 12,700 acres of dense young forest areas (mostly silver fir-hemlock types in the upper CRMW) that are suitable for restoration thinning (Figure 8). The areas tentatively planned for restoration thinning through 2008 were selected because they 1) fit all the site selection criteria (Section 5.3); 2) provide connectivity between existing old growth forest areas; 3) coordinate with road decommissioning plans; and 4) consist of large project areas which are more economical to implement. It is anticipated that all areas that would benefit from restoration thinning will be thinned during the course of the CRW-HCP, except some area that are intentionally left untreated for comparison purposes. There are many more acres of dense forest that has passed the point at which restoration thinning could be implemented (the trees are too large), and only a portion of these dense forests will undergo ecological thinning.

Figure 8. Past, present, and near-term restoration thinning project sites in the CRMW.



7.3 Near-Term Upland Planting Projects

No areas were identified from an analysis of current data as potential upland forest planting sites. Upland planting, therefore, will most likely occur in the near-term in association with ecological and restoration thinning projects with the goal of diversifying the plant community, both overstory and understory. Specific locations of planting projects will be identified during the thinning planning process, following the collection of forest inventory data on a relatively fine scale (e.g., one plot every few acres) which will identify areas that would benefit from diversification.

On a landscape scale in the CRMW, there may be the need to plant non-traditional species, such as lichens, mosses, and mistletoe. In order to determine this need, an assessment is in order to identify the distribution and abundance of key species. Once this assessment is completed, planting of these non-traditional species would occur in an experimental manner (Borsting, 2004).

7.4 Long-Term Upland Forest Restoration Projects

The methodology described in this document and used to identify near-term forest restoration projects will be used to identify projects in the long-term as data under development, and other future datasets, become available (see Section 6.3). Upland restoration planting projects may incorporate planting non-tree species (e.g., lichens) in second-growth forests as appropriate feasibility information is developed over time. Priorities in the upland forest restoration program may change over time.

8.0 BENCHMARKING, MONITORING, RESEARCH, AND ADAPTIVE MANAGEMENT

8.1 Benchmarking

Benchmarking is the comparison of the Upland Forest Restoration Program at the WMD to other similar programs in the western Cascade Mountains in Washington, the Pacific Northwest, and beyond, to validate that the restoration being conducted in the CRMW employs the most current science and uses appropriate methods in achieving the stated goals. The programs and projects mentioned in Appendix A, and others as they are planned and implemented, will be monitored by WMD staff over time, so that methods implemented in the CRMW are the best available in achieving the CRW-HCP goals. WMD staff will keep appraised of current scientific forest restoration literature, attend forest restoration workshops and conferences, and host workshops with other professionals to discuss forest restoration techniques and findings.

In the development of this plan, the CRW-HCP, the 45 Road Forest Restoration Project Plan, and the 700 Road Forest Restoration Project Plan, many regional experts in forest restoration and/or other fields of forest ecology were consulted. They include:

- Dean Berg (Silvicultural Engineering)
- Andrew Carey (Pacific Northwest Research Station, U.S. Forest Service);
- Chuck Chambers (Emeritus, Washington Department of Natural Resources);
- Bob Curtis (Pacific Northwest Research Station, U.S. Forest Service);
- Jerry Franklin (College of Forest Resources, University of Washington);
- Jan Henderson (U.S. Forest Service, Mt. Baker-Snoqualmie National Forest);
- John Tappeiner (Forest Resources, Oregon State University);
- Walter Thies (Pacific Northwest Research Station, U.S. Forest Service);

Consultation with regional experts on various aspects of forest restoration will continue throughout the course of the CRW-HCP, including aspects of best management practices, research results, monitoring, and plan review.

8.2 Project Monitoring

The CRW-HCP discusses four primary types of monitoring that will be applied to upland forest restoration projects:

- *Compliance monitoring* is required for all restoration projects, and is designed to ensure that specifications in restoration plans and contracts are met.
- *Effectiveness monitoring* examines the degree to which restoration actions and techniques meet the specified ecological objectives. Scientific project teams will delineate objectives and develop hypotheses about the type and magnitude of changes expected by restoration actions. Effectiveness monitoring will assist in answering the question: "Did the project result in the anticipated, positive changes in ecological or habitat value?" Using a framework developed by numerous conservation organizations (e.g., Kernohan and Haufler 1999, Parrish et al. 2003, and Levy et al. 2003), effectiveness monitoring of forest restoration projects in the CRMW will have three components:

    1. identify a limited number of key ecological attributes (e.g., focal restoration targets) based on a conceptual model of forest succession;
    2. identify measurable future conditions for these attributes, including an acceptable range of variation; and,
    3. periodically assess whether restoration actions have yielded desired outcomes and institute adaptive management (see below).

    This type of monitoring will be done for selected individual projects and will be designed in conjunction with adaptive management monitoring to evaluate the effectiveness of upland forest restoration techniques across several projects and areas (see section 9.3).

- *Adaptive management* is a key monitoring component because of the experimental nature of many of the restoration actions and techniques, and the uncertainty about the outcomes. In addition, research projects may be required to investigate poorly understood upland forest processes, and to test assumptions about cause-effect relationships (e.g., understory tree, shrub, and herb response to different thinning treatments). These types of monitoring will involve hypothesis development, rigorous project and sampling designs, data collection and evaluation, then applying the results to future projects in the form of modifications and improvements in techniques, design, and implementation. The focus will primarily be on habitat (plant) variables, rather than animal monitoring, because of the difficulty and expense involved in sampling animal populations. Some limited monitoring of animal species that are indicators of certain ecological functions or conditions may be done, however, in certain situations.
- *Long-term trend monitoring* looks at how forest habitat is changing on the CRMW landscape over the course of the CRW-HCP. Monitoring at this scale is being managed in conjunction with the Monitoring and Water Characterization ID Teams.

All three types of upland forest restoration projects (section 2.1) will be monitored for compliance, but effectiveness and adaptive management monitoring may vary among the activities with respect to variables measured, sampling design, duration, and frequency. The cost of monitoring will be accounted for in individual project implementation costs.

8.2.1 Ecological Thinning Project Monitoring

8.2.1.1 Compliance Monitoring

A designated WMD staff member will conduct compliance monitoring of the implementation of ecological thinning projects on the ground throughout the implementation period. This will include ensuring that the project management plan is being followed through the application of treatments, most likely through a contract for private professional services (see Section 9.2). A post-treatment forest inventory may be conducted to validate that the prescriptions resulted in expected conditions.

8.2.1.2 Effectiveness Monitoring

The initial ecological thinning projects under the CRW-HCP will be individually monitored for effectiveness of treatments, with the complete monitoring plans delineated in the Site Management Plans. The management plans will include appropriate literature reviews, identify key forest processes and monitoring questions, state scientific hypotheses about the ecological response to the thinning treatments, describe desired future conditions, specify the sampling design and schedule, and estimate monitoring costs. There will likely be several different thinning treatments within each project, which may consist of creating various sizes of skips and gaps; varying density, spacing, and size of leave trees; changing the proportion of leave tree species and sizes; and creating snags and downed wood. Restoration planting of trees, shrubs, or other species such as lichen, may also be a part of the management plan. Control areas will be associated with the treatment site for each project. At a minimum, monitoring will use treatment/control comparisons. Whenever possible, the monitoring design will utilize a pre- and post-treatment/control design. If there are any comparable late-successional sites, they will also be sampled and used as a reference for target conditions. When appropriate, historical data from the pre-harvest forest on the site may be reconstructed through stump records.

Effectiveness monitoring of ecological thinning projects will measure these key ecological attributes for the focal forest restoration targets:

- tree diameter growth;
- tree canopy development;
- overall species diversity;
- structural complexity (e.g., variable tree density, snags, downed wood);
- spatial heterogeneity;
- understory development; and,
- habitat connectivity.

These variables will be measured at monitoring plots similar to PSPs, and are expected to include measures of trees (e.g., species, diameter, height, canopy strata, live crown ratio), shrubs (e.g., species, height), herbs (e.g., species, percent cover, height), snags (e.g., diameter, height, decay class, species), and downed wood (e.g., diameter, length, volume, decay class, species). Sample plot density and frequency of sampling will be site-specific, though it is anticipated that the first data collection after the ecological thinning will occur within five to ten years. Habitat connectivity will be assessed through landscape metrics such as amount of late-successional forest habitat, distance to nearest late-successional forest habitat, patchiness, and edge/interior ratio. Since significant uncertainty exists as to the degree of effect ecological thinning will have in reducing the time of the competitive exclusion stage of forest succession and increasing the diversity and complexity of forest habitat, an acceptable range of variation for each attribute in thinning areas, as compared to controls, is difficult to determine for rating restoration success. Our modest initial goals are to increase or improve each of these attributes within 10 years of project implementation.

The occurrence of wildlife species that utilize late-successional characteristics (such as bats or certain insect species) may be used to experimentally validate the success of the ecological thinning treatments. If restoration planting is part of the prescription, plant survival will be monitored annually for the first three years.

After each data collection period, both metadata (including a detailed description of methods) and the data collected will be entered into a central database, consistent with recommendations from the Watershed Characterization ID Team. The data will be analyzed, and a report written in which the results will be compared with the ecological objectives, and success to date evaluated. Because of the critical importance of maintaining water quality in the CRMW, if any ecological thinning project has the potential to impact water quality during or after the project, water quality parameters will be closely monitored and reported.

8.2.1.3 Adaptive Management Monitoring

Due to limited staff time and funding, not all ecological thinning projects will be monitored. Instead, a system of coordinated adaptive management monitoring will be instigated to strategically identify projects that should be monitored. Ecological thinning adaptive management monitoring will be used to modify future management prescriptions, if necessary, in an attempt to maximize the ecological benefits. Continued benchmarking with other restoration programs and the effectiveness monitoring data for all monitored projects will be combined to examine the effectiveness of ecological thinning techniques and treatments in various habitat types. Details of adaptive management monitoring will be developed as sites for ecological thinning are selected and prioritized.

In general, we predict that ecological thinning treatments will accelerate development of late successional forest characteristics compared with similar untreated areas. These characteristics should include increased species diversity (tree, shrub, herb, cryptogam, animals), greater horizontal structural diversity (e.g., canopy gaps, areas of denser forest or anti-gaps), increased vertical structural diversity (e.g., multiple vegetation layers), larger and more varied tree sizes (both diameter and height), and increased amounts of dead wood (snags and downed wood). We also predict that the thinning treatments will influence natural processes such as tree growth and regeneration, canopy differentiation, and understory tree, shrub and herb development.

The primary key questions for adaptive management monitoring of ecological thinning are:

- In general, how effective is ecological thinning at accelerating late-successional characteristics and facilitating natural processes compared with untreated areas?
- How do different ecological thinning prescriptions (e.g., number and size of gaps, leave tree density and spacing) compare with respect to accelerating late-successional characteristics?
- How do results of a particular ecological thinning prescription compare between forests at different elevations, with different dominant tree species, of different site quality, and/or with different initial forest conditions, and how does this change over time?
- How do the characteristics and processes in ecologically thinned forests compare with late-successional and old-growth forests?
- What is the response of exotic plants and animals to ecological thinning?

8.2.2 Restoration Thinning Project Monitoring

8.2.2.1 Compliance Monitoring

A designated WMD staff member will conduct compliance monitoring of the implementation of restoration thinning projects on the ground throughout the implementation period. This will include ensuring that the project management plan is being followed through the application of treatments through a contract for professional services (see Section 9.2). Compliance monitoring of restoration thinning includes modified forest inventory plots throughout the project area that indicate tree density by species.

8.2.2.2 Effectiveness Monitoring

Effectiveness monitoring of restoration thinning projects will measure these key ecological attributes for the focal forest restoration targets:

- tree competition;
- light penetration (e.g., understory development and diversity);
- tree growth;
- long-term fire hazard (e.g., forest fuels);
- chance of catastrophic loss; and,
- temporal extent of competitive exclusion stage.

The modified forest inventory plots taken during compliance monitoring will also serve for short-term effectiveness monitoring of restoration thinning projects. Variables will also be measured at monitoring plots similar to PSPs, and are expected to include measures of trees (e.g., species, diameter, height), shrubs (e.g., species, height), herbs (e.g., species, percent cover, height), snags (e.g., diameter, height, decay class, species), and downed wood (e.g., diameter, length, volume, decay class, species). Sample plot density and frequency of sampling will be site-specific, though it is anticipated that the first data collection after the restoration thinning will occur within five to ten years. Since uncertainty exists as to the degree of impact restoration thinning will have in limiting the temporal extent of the competitive exclusion stage of forest succession, an acceptable range of variation for each attribute in thinning areas, as compared to controls, is difficult to assess in rating restoration success. Our modest initial goals are to reduce competition among trees (as measured by growth rates), fire hazard (as measured by fuel loads), chance of catastrophic loss (as measured by frequency of incidence), and time in the competitive exclusion stage. Additionally, we aim to increase light penetration (as measured by understory development) and tree growth (as measured by dbh).

8.2.2.3 Adaptive Management Monitoring

Adaptive management monitoring of restoration thinning treatment types (including leave tree density and spacing, and proportion of tree species) across different forest habitats will incorporate a pre- and post-treatment and control design. The primary key questions for adaptive management monitoring of restoration thinning are:

- In general, how effective is restoration thinning at moving forest areas more quickly through the competitive exclusion stage, compared with untreated areas?
- How do different restoration thinning prescriptions (leave tree density and spacing) compare with respect to accelerating forest development?
- How do results of a restoration thinning prescription compare between forests at different elevations, with different dominant tree species, of different site quality, and/or with different initial forest conditions, and how does this change over time?
- How does forest development after restoration thinning compare with “natural” stand development processes?
- What is the response of exotic plants and animals to restoration thinning?

Variables to be measured include tree species, density, dbh, height, age, and percent live crown. Number and location of sample plots will be determined as restoration thinning site selection and prioritization are completed. Initial results from restoration thinning adaptive management monitoring will be used to modify future management prescriptions, if necessary, to maximize the ecological benefits. Restoration thinning is expected to be completed by 2016 (as stated in the CRW-HCP), after which there will no longer be any young forests in need of this type of thinning in the CRMW. As a result of this short time frame, adaptive management monitoring will occur yearly, to allow collection of the maximum amount of information on which to base decisions about prescription modifications.

8.2.3 Upland Restoration Planting Project Monitoring

8.2.3.1 Compliance Monitoring

A designated WMD staff member will conduct compliance monitoring of the implementation of upland planting projects on the ground throughout the implementation period. This will include ensuring that the project management plan is being followed through the application of treatments, most likely through a contract for professional services (see Section 9.2), with volunteers, or with WMD staff. Compliance monitoring of upland planting includes modified inventory plots throughout the project area that indicate short-term plant survival.

8.2.3.2 Effectiveness Monitoring
Effectiveness monitoring of upland planting projects will address two aspects of planting: success of planted individuals and changes in the larger treatment area. Planting sites will be marked for monitoring and measurements will include survival, growth, and reproduction (are new individuals establishing on the site from the parent plant, is the parent plant growing, etc.). Data will be collected in plots spread throughout the treatment unit to measure changes in species composition and diversity across the entire forest area. Monitoring at the stand scale will also examine effectiveness of planting at achieving the desired restoration goal(s). For example, if shrubs are planted as arthropod habitat, arthropod diversity will be sampled before and after planting.

Project effectiveness monitoring will occur the first year and at least twice more in the next five years after planting to assess immediate survival rates. Although monitoring of process changes should also be done in the first five years, it will be important to repeat this monitoring over the longer-term because changes may not be apparent for several years or initial changes may shift over time. Additional monitoring will occur on a longer-term basis as appropriate to the species planted.

8.2.3.3 Adaptive Management Monitoring
We predict that upland planting will help accelerate the development of biological diversity in forest areas. This increase in diversity will have impacts on wildlife habitat, soil development, and forest structural diversity. Adaptive management monitoring questions for upland planting will include:

- How do planted and unplanted thinning treatments respond differently with regards to establishment of planted species?
- How do different tree retention prescriptions (both pattern and density) affect plant species diversity?
- How does planting alter ecosystem processes, such as dispersal and reproduction of certain floral species?
- What is the response of exotic plants and animals to upland planting?

Because we will be pioneering new restoration planting techniques, some of the upland planting projects would serve well as formal research projects. It will be important to utilize controls, pre-treatment sampling, and structure the projects in such a way that statistical analyses can be used to compare the results. Research questions will explore the success and applicability of the experimental techniques. Questions will include:

- Is cover or density of the planted species greater in planted sites than unplanted?
- How do cost, establishment rates, survival rates, and ease of implementation differ between different techniques?

- Does planting influence the larger goals intended by the project (e.g., increase wildlife browse; diversify canopy structure)?

8.3 Monitoring Landscape-level Long-term Trends

The CRW-HCP mandates that long-term trends in upland forest habitat be monitored, so landscape-level affects of the CRW-HCP, including forest reserve status, forest growth and succession, and forest restoration, can be documented and tracked through time (CRW-HCP 4.5-28). Monitoring long-term trends in upland forests has two primary objectives: 1) to increase scientific knowledge about upland forest processes and functions, and 2) to track changes in forest habitat through time (including both extent and condition). Though this monitoring effort falls in jurisdiction of the Watershed Characterization and Monitoring ID Teams, it is mentioned here to demonstrate that large-scale upland forest habitat issues are also being monitored in the CRMW.

Several key questions will be used to frame the monitoring of long-term trends in the upland forests:

- What is the extent and condition of upland forests in the CRMW (including all ages of second growth and old-growth forests) and how are these changing through time?
- What key upland forest processes are influenced by restoration activities and how do they change over time as a result of the management?
- Have upland forest restoration activities achieved the objective of accelerating late-successional characteristics, compared with untreated areas?
- Have any upland forest processes been negatively influenced by forest restoration activities?
- How is the forested landscape changing as a result of changing climatic conditions?
- What is the extent of exotic plant invasion in upland forest in the CRMW and how is it changing over time?
- Have selected species of concern (e.g., northern spotted owl, marbled murrelet) benefited from upland forest restoration projects?

9.0 STANDARDS AND GUIDELINES FOR PROJECT PLANNING AND IMPLEMENTATION

The UFRIDT will identify upland forest restoration projects and recommend membership for project teams, usually consisting of three to four people with appropriate expertise. These recommendations will be presented to the Ecosystem Section Manager and Work Unit Leads, who will have final approval of all projects and project team composition. The project team will conduct an in-depth analysis, design the project and prepare a project management plan. The Forest Ecology work group will coordinate field layout (e.g., boundary tags and right of way marking), required permit application and acquisition, appraisal, contracting, and where applicable, city ordinance acquisition.

9.1 Project Plan Development

Once project sites are selected (see Sections 5.0 and 6.0), project teams will develop project management plans that describe the restoration project. In some cases multiple restoration projects will be components of one management plan. For example, an ecological thinning project may have an upland restoration planting project as an integral part of the overall goals and objectives. In this case one project plan would incorporate both the ecological thinning and the upland restoration planting components.

Format of project plans will generally follow the outlines provided in Appendix F. Project plans are intended for a varied audience (from the general public to experts) and their value is both immediate and long-term. The plan will serve as an implementation guide as well as providing detailed information to interest groups regarding HCP-related activities. These plans will provide information to City Council members and staff, especially where city ordinances are required (as in ecological thinning). The plans will also provide an historical perspective of HCP-related restoration activities and information necessary for long-term monitoring activities.

Project plan development will generally include the following steps:

- delineate site boundaries based on ecological characteristics and logistics;
- obtain site description and forest inventory data, if needed;
- identify project goals, objectives, and desired future conditions;
- identify key ecological processes;
- state hypotheses guiding interventions and affects on processes, including conceptual models;
- identify measurable indicators of processes;
- describe monitoring activities, including hypotheses and indicators, protocols, and sampling schedules;
- develop silvicultural prescriptions and examine alternatives;
- develop transportation and yarding plans as applicable;
- conduct a cultural resource survey;
- perform a risk analysis, including any potential affects on water quality, as well as an analysis of the risks and uncertainties both of implementing the project and of leaving the area untreated;
- perform a cost/benefit analysis, considering the total project costs and the relative ecological benefit; and
- develop an implementation schedule.

The development of silvicultural prescriptions will stem from the ecological objectives and desired future conditions of the restoration project, using the best available science. The Project Team must consider operational feasibility during project design. The transportation system must meet the regulatory requirements, and pose no long-term environmental risk. New road construction will be avoided.

Throughout prescription development, the project team will solicit input from WMD interdisciplinary teams, professional consultants, or scientists with appropriate expertise, as well as consulting current scientific literature. Prescriptions will be site-specific, but may also address larger monitoring and research questions as appropriate within the CRMW. If a restoration project is being planned and implemented with an adaptive management approach, there should be specified objectives related to learning (i.e., reducing uncertainty and increasing our understanding of ecological processes and methods to restore those processes). The monitoring component of the plan should elaborate on these objectives, including the development of questions and hypotheses for each objective. The monitoring plans contained within project plans will be sent to the Monitoring ID Team for review.
The plan should describe the relationship of this project to other upland, riparian, aquatic, or road restoration projects. If the project is part of a sub-basin-scale set of projects, a brief description of the sub-basin restoration plan should be provided and reference made to any larger plan of which this project is a part.

Project plans will be reviewed by appropriate WMD staff and may be sent to external experts for review. In addition, other interested parties (including environmental organizations such as the Sierra Club and Biodiversity Northwest, Tribes, and neighboring landowners) will be contacted and their input solicited. The intent of this public outreach and involvement is to share CRW-HCP restoration objectives and activities with a varied audience. The ideal result will be that the public is informed about and supports the restoration activities implemented in the CRMW. For ecological thinning projects, the project plan will accompany the ordinance to the Mayor's office for staff review. If appropriate, comments from the Mayor and City Council members will be incorporated into the final project plan. Staff will also present information on upland forest restoration activities in the CRMW to a broader audience, including presentations at workshops, symposiums, and conferences. When appropriate, on-site workshops, lectures, and field tours relating to restoration activities will be hosted by WMD staff.

9.2 Project Implementation

Once the project plan is complete, the Forest Ecology work group, in conjunction with the project team, will oversee project implementation. Components will generally include:

- layout of boundaries, roads, and yarding systems;
- contract development, including development of clear specifications for project implementation (i.e., criteria for how trees are selected for thinning, limitations regarding snags, downed wood, leave trees, etc.);
- contract award;
- baseline monitoring;
- compliance monitoring during treatment implementation;
- post-treatment monitoring; and,
- project evaluation and reporting.

City of Seattle Contract Support Services will be utilized to assist designated WMD staff in contract language development, advertisement, contract award, and subsequent payment.

The project team will ensure that seasonal ecological issues (e.g., access issues, sensitivity of trees to bark damage, nesting seasons) are taken into consideration during project implementation. Data collected for project planning, baseline monitoring, compliance monitoring, costs, and other purposes will be compiled, formatted, and stored in the appropriate files, as designated by the Watershed Characterization ID team.

It is anticipated that at least a 62-acre ecological thinning project will be implemented annually over the course of the CRW-HCP. Larger projects may be planned, up to 500 acres, and implemented over several years. Each ecological thinning project will be subject to a 3-year effort including phase I (site selection and prioritization), phase II (planning), and phase III (implementation). In any given year there will be at least one project in each of the phases. Similarly, it is anticipated that restoration thinning will occur on at least 600 acres annually until all relevant forests are treated. The effort to complete individual restoration thinning projects will generally be subject to a 2-year timeline, combining phases I and II into a single planning year. Upland planting projects will be applied primarily in conjunction with ecological thinning and restoration thinning projects and have unspecified annual target levels, although the HCP specifies that 1000 acres will be planted over 50 years.

9.3 Coordination with Other Restoration Projects

The UFRIDT will oversee coordination with other restoration projects by participating in basin level planning efforts and working with the Monitoring ID team. This coordination will address such issues as selecting project sites that best fit into the long-term basin restoration plan, timing of road decommissioning, timing of construction projects, and coordination of monitoring.

9.4 Project Budgets

Project costs will be tracked throughout the planning, implementation, and monitoring phases of every project. Administered by the Forest Ecology work unit lead, staff time and contract costs will be tracked through the City financial tracking system. No projects are allowed to exceed the annual budgets allotted under the CRW-HCP, unless alternative funding sources have already been secured (e.g., BPA Mitigation Fund). Any revenues resulting from the sale excess thinned trees that are removed from project sites will be deposited in the SPU Water Fund to offset costs of HCP implementation. A portion of these revenues may be used to offset upland forest restoration planning and implementation costs, but this budget authority must be approved by the Seattle City Council via an ordinance.

10.0 OVERSITE ROLE OF THE UPLAND FOREST RESTORATION ID TEAM

Upland Forest Restoration ID Team will remain active through the completion of the Upland Forest Restoration Strategic Plan. Once this planning process is completed, the ID Team will focus efforts in two areas. First, the Upland Forest Restoration ID Team will assist with implementing adaptive management, in partnership with the Monitoring and Watershed Characterization ID Teams. Through the Adaptive Management program, the ID Team will help to coordinate individual restoration project selection and design, such that the key questions can be addressed through consistent planning and monitoring. Coupled with this role, the ID Team will review individual project management plans and provide guidance on the design of those plans such that they are consistent with this Strategic Plan. In addition, members of the team will analyze monitoring data as they become available to continue to refine and improve techniques for upland forest restoration, again, in coordination with the Monitoring and Watershed Characterization ID Teams. Second, the ID Team will establish a review process to track and facilitate the collection of data that will serve to inform long-range site selection and prioritization. The ID Team, will not, however, oversee all activities of the project teams that are working directly on individual project plans, but rather serve to ensure consistency and long-term vision to the range of individual project that are planned and implemented.

The Upland Forest Restoration ID Team's approach will continue to be refined within a strategic watershed restoration framework that includes riparian, aquatic, and road restoration. Focusing on our particular conservation goals, the strategic framework entails developing a vision for the future of the watershed by specifying desired future conditions for the forest and other habitats that are based on the identification of key ecological attributes of the watershed ecosystem. The approach addresses, in a direct fashion, any threats that may exist to achieving those future conditions. Such threats include constraints imposed by existing conditions, the potential effects of global climate change on plant and animal communities, and development in surrounding areas. The framework also identifies the potential actions that might be taken and the key indicators that can be measured to track progress toward the desired future conditions.

An important feature of this strategic framework is the need to identify and address uncertainties and knowledge gaps. The approach includes risk mitigation in the face of uncertainty and development of an intentional learning model for management over the long term. Key research needs are being identified based on knowledge gaps that reduce our chances of success with our conservation goals. Monitoring and adaptive management based on key indicators are being pursued over the long term so that decisions can be made with greater confidence and projects can be designed and implemented with a greater chance of success over time. The development of this overarching strategic framework is still in progress.

Glossary

Adaptive Management – As applied in the CRW-HCP, the process of adaptive management is defined with three basic elements: 1) an initial operational decision or project design made in the face of uncertainty about the impacts of the action; 2) monitoring and research to determine the impacts of the actions; and, 3) changes to operations or project design in response to new information.

Aspect – The direction a slope faces with respect to the cardinal compass points. For example, a hillside facing east has an eastern aspect.

Basal Area – The cross sectional area of a tree at breast height, usually summed by species over a given area.

Biodiversity – Biological diversity; the combination and interactions of genetic diversity, species composition, and ecological diversity in a given place at a given time.

Biological Legacies – As defined in the CRW-HCP: Features of a previous forest that are retained at timber harvest or left after natural disturbances, including old-growth or other large diameter snags, stumps, live trees, downed wood, soil communities, deciduous trees, and shrubs. Also referred to as legacies.

Canopy – The cover of branches and foliage formed collectively by the crowns of trees or other growth. Also used to describe layers of vegetation or foliage below the top layer of foliage in a forest, as when referring to the multi-layered canopies or multi-storied conditions typical of ecological old-growth forests.

Canopy Closure – The degree to which boles, branches, and foliage (canopy) block penetration of sunlight to the forest floor.

Cedar River Municipal Watershed (CRMW) – An administrative unit of land owned by the City of Seattle for the purposes of providing a municipal water supply. The 90,546-acre municipal watershed within the upper part of the Cedar River Basin lies upstream from the City's water intake at Landsburg Diversion Dam. It is composed of eight major sub-basins and 27 sub-basins, 26 of which drain into the Cedar River. It supplies about 2/3 of the drinking water to Seattle Public Utilities' water service area.

Clearcut – A silvicultural system involving the removal of nearly all standing trees within a given harvest area.

Co-Dominant Trees – Trees or shrubs with crowns receiving full light from above, but comparatively little from the sides. Crowns usually form the general level of the canopy.

Competitive (Stem) Exclusion – A phase of forest succession in which the canopy closes and competition among trees becomes intense in a developing forest area.

Compliance Monitoring – Monitoring performed to determine whether CRW-HCP programs and elements are implemented as planned.

Conifer Trees – A tree belonging to the taxonomic order Gymnospermae, and comprising a wide range of trees that are mostly evergreen. Conifers bear cones and have needle-shaped or scale-like leaves.

CRW-HCP – Cedar River Watershed Habitat Conservation Plan; see Habitat Conservation Plan.

Decay Class – One of five recognizable stages of wood decay as a fallen tree decomposes and is reincorporated into the soil. Factors that categorize stages of decay include bark and twig presence or absence, log texture and shape, wood color, position relative to the ground, and presence or absence of invading roots (Maser and Trappe 1984).

Deciduous Trees – Flowering trees, belonging to the taxonomic order Angiospermae, with relatively broad, flat leaves, as compared to conifers or needle-leaved trees.

Diameter at Breast Height (dbh) – The diameter of a tree in inches, including bark, measured 4.5 feet above the ground on the uphill side of the tree.

Disturbance – Significant change in forest structure or composition through natural events (such as fire, flood, wind, earthquake, or disease) or human-caused events (forest management).

Dominant Tree – Trees with crowns receiving full light from above and partly from the side; usually larger than the average trees in the forest area, with crowns that extend above the general level of the canopy and that are well developed but possibly somewhat crowded on the sides. A dominant tree generally stands head and shoulders above all other trees in its vicinity.

Downed Wood – Large pieces of wood in forests, including logs, pieces of logs, and large branches.

Ecological Thinning – As defined in the CRW-HCP: The silvicultural practice of cutting, damaging, or otherwise killing some trees from some areas of older, overstocked, second-growth forest (typically over 30 years old). The intent of ecological thinning is to encourage development of the habitat structure and heterogeneity typical of late-successional and old-growth forest areas, characterized by a high level of vertical and horizontal forest structure, and to improve habitat quality for wildlife. It is expected that techniques will include variable-density thinning to create openings, develop a variety of tree diameter classes, develop understory vegetation, and recruit desired species; and creating snags and downed wood by uprooting trees, felling trees, topping trees, injecting trees with decay-producing fungus, and other methods. Ecological thinning does not have any commercial objectives. However, in those cases in which an excess of woody material is generated by felling trees, trees may be removed from the thinning site and may be sold or used in restoration projects on other sites.

Ecosystem Function – The roles played by the living and nonliving components of ecosystems in driving the processes (e.g., carbon, water, and nutrient cycles) that sustain the ecosystem.

Ecosystem Process – Something that is going on in the ecosystem; a natural phenomenon in an ecosystem that leads toward a particular result.

Effectiveness Monitoring – Monitoring to determine whether implemented CRW-HCP conservation strategies result in anticipated habitat conditions or effects on species.

Epicormic Branching – Branches that sprout from the bole of a tree, usually when it is subjected to increased sunlight.

Even-Aged Forest – A forest area with minimal differences in age between trees, generally less than 10 years.

Forest Inventory – An assessment of forest resources that describes the location and nature of forest cover (including tree size, age, volume, and species composition) as well as a description of other forest values such as snags, downed wood, soils, vegetation, and wildlife features.

Forest Area – A group of trees that possess sufficient uniformity in composition, structure, age, spatial arrangement, or condition to distinguish them from adjacent groups of trees.

Forest Structure – The arrangement of the physical parts of the forest ecosystem, both vertically and horizontally.

Forest Succession – The sequential change in composition, abundance, and patterns of species that occurs as a forest matures after an event in which most of the trees are removed. The sequence of biological communities in a succession is called a sere, and they are called successional or seral stages.

Geographic Information System (GIS) – A computer system for collecting, storing, retrieving, transforming, displaying, and analyzing spatial or geographic data, linking areas or map features with associated attributes for a particular set of purposes, including the production of a variety of maps and analyses.

Habitat – The sum total of environmental conditions of a specific place occupied by plant or animal species or a population of such species. A species may require or use more than one type of habitat to complete its life cycle.

Habitat Connectivity – A measure of the extent to which conditions between different areas of similar or related habitat provide for successful movement of fish or wildlife species, supporting populations on a landscape level.

Habitat Conservation Plan (HCP) – As defined under Section 10 of the federal Endangered Species Act, a plan required for issuance of an incidental take permit for a listed species. Called "conservation plans" under the Act, HCPs can address multiple species, both listed and unlisted, and can be long term. HCPs provide for the conservation of the species addressed, and provide certainty for permit applicants through an implementation agreement between the Secretary of the Interior or Secretary of Commerce and a non-federal entity.

Habitat Heterogeneity – The degree of variation of physical forms across an area of forest that provide a variety of habitat niches. See "forest structure" and "structural complexity".

Interior (Core) Forest Conditions – Forest conditions that are not largely affected by edge effects, which occur where large openings abut the forest. Edge effects that are know to occur in some areas include penetration of light and wind, temperature changes, and increased predator activity. Interior forest conditions are achieved at sufficient distance from an edge so that edge effects are minimal.

Landscape – A large regional unit of land that typically includes a mosaic of biological communities.

Late-Successional Forest – Forest in the later stages of forest succession (e.g., after the competitive exclusion stage), the sequential change in composition, abundance, and patterns of species that occurs as a forest matures. As used in the CRW-HCP, refers to conifer forests 120-189 years of age. Characterized by increasing biodiversity and forest structure, such as a number of canopy layers, large amounts of downed wood, light gaps (canopy openings), and developed understory vegetation.

Lower Watershed – That area of the Cedar River Municipal Watershed generally west and south of Cedar Falls which largely drains to the mainstem of the Cedar River downstream of Masonry Dam.

Mean Annual Increment – The annual average growth rate for a tree.

Metapopulation – A set of local populations connected by migrating individuals.

Monitoring – The process of collecting information to evaluate if objectives and anticipated results of a management plan are being realized or if implementation is proceeding as planned. This may include assessing the effects upon a species' habitat.

Old-Growth Forest – As used in the CRW-HCP, native, unharvested conifer forest in the Cedar River Municipal Watershed that is at least 190 years of age.

Old-Growth Forest Conditions – Conditions in older conifer forest areas, with vertical and horizontal structural attributes sufficient to maintain some or all of the ecological functions of natural "ecological old-growth" forest, which is typically at least 200 years old and often much older.

Overstory – That portion of the trees, in a forest of more than one story, forming the upper or uppermost canopy layer.

Quadratic Mean Tree Diameter (Qdbh) – The diameter at breast height (dbh) of a tree of average basal area in a given forest area; generally slightly larger than the average dbh.

Regeneration – The seedlings and saplings existing in a forest area; the act of establishing young trees naturally or artificially (replanting).

Relative Density (RD) – A measure of tree density in a forest area indexed to an observed maximum for a species over various diameters; generally describes tree growth potential based on density. As defined by Curtis (1982), relative density for Douglas-fir is $BA/(Qdbh^{0.5})$, where BA is basal area and Qdbh is the quadratic mean stand diameter, and ranges from 0 to 100.

Restoration Planting – Planting of native trees, shrubs, and other plants to encourage development of habitat structure and heterogeneity, to improve habitat conditions for fish and wildlife, and to accelerate development of old-growth forest conditions or riparian forest function in previously harvested second-growth forest.

Restoration Thinning – As used in the CRW-HCP, a silvicultural intervention strategy applied in the Ecological Reserve in areas of young (usually 10 to 30 year-old) over-stocked forest with the intent of increasing biological diversity and wildlife habitat potential, accelerating the development of mature forest characteristics, and minimizing the amount of time a forest area remains in the competitive exclusion stage (a stage characterized by minimal light penetration and low biological diversity). This strategy protects water quality by reducing the risk of large scale catastrophic damage to the watershed (primarily through development of windfirmness and increased resistance to insect attack, which is exacerbated by the stress on intense competition among trees). Techniques for restoration thinning include cutting, girdling, or otherwise killing some trees in variable density thinning patterns, retaining a mix of species that is characteristic of natural site conditions, and leaving small gaps or openings characteristic of naturally regenerated forests that result from small natural disturbances such as wind or disease.

Second-Growth Forest – Forest areas in the process of regrowth after an earlier cutting or disturbance.

Seral Stage – A particular stage (ecological community) in a sere, or pattern of succession. As used in the CRW-HCP, applies to forest succession.

Silviculture – The theory and practice of controlling the establishment, composition, growth, and quality of forest areas in order to achieve management objectives. Includes such actions as thinning, planting, fertilizing, pruning, and leaving seed trees at harvest.

Site Class – A classification of forestland based on ecological factors (e.g., soils) tree growth potential.

Slope – A measure of the steepness of terrain, equal to the tangent of the angle of the average slope surface with the horizontal, expressed in percent. A 100 percent slope has an angle with the horizontal of 45 degrees.

Snag – A standing dead tree.

Structural Complexity – The degree of variation of physical forms across an area of forest (e.g., tree density, tree size, canopy layering, snags, downed wood, understory vegetation). See “forest structure” and “habitat heterogeneity”.

Successional Stage – Phases of forest development have been identified as various stages; generally as stand initiation, competitive exclusion, understory reinitiation, and old-growth forest stages (Oliver 1981), although development complexity has also been recognized (Franklin et al. 2002). See “forest succession”.

Tree Density – The number of trees over a given area. Traditionally this has been expressed as trees with a commercial value (e.g., greater than 6 inches dbh) per acre. For forest restoration in the CRMW, it is more appropriate to look at tree density in terms of canopy strata.

Understory – All forest vegetation (e.g., herbs, shrubs, seedlings, smaller saplings) growing under an overstory (e.g., taller trees and shrubs).

Upper Watershed – That area of the Cedar River Municipal Watershed generally east of Cedar Falls which drains to the Chester Morse Lake Basin.

Watershed – A basin contributing water, organic matter, dissolved nutrients, and sediments to a stream, lake, or ocean. As applied in the CRW-HCP, used also to refer to the Cedar River Municipal Watershed above the Landsburg Diversion Dam and water intake, some of which does not drain into the Cedar River above the Landsburg water intake.

Windthrow (aka Blowdown) – Trees felled by high wind.

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Appendix A. Selected studies related to ecological thinning, restoration thinning, and upland planting in the CRMW.

Olympic Habitat Development Study. The principal investigators for this study are Andy Carey and Connie Harrington with cooperators from the Pacific Northwest Research Station (PNW) of the US Forest Service (USFS), Washington Department of Natural Resources (WDNR), University of Washington (UW), and Olympic National Forest (ONF) (http://www.fs.fed.us/r6/olympic/ecomgt/research/habitat.htm and Reutebuch et al. 2002).

- *Goals*: Accelerate development of plant and animal communities and structures typical of late-successional/old-growth forests.
- *Sites:* Blocks of 30 to 70 year-old forest in the Adaptive Management Area (AMA) of the Olympic National Forest on the Olympic Peninsula in western Washington.
- *Methods*: The project includes implementing variable density thinning treatments in a randomized block design experiment. Each of eight blocks contain four or five 15- to 25-acre treatment plots. Treatments used a "thin from below" prescription (e.g., 209 trees per acre thinned to 135, 319 trees per acre thinned to 245) leaving a proportion of canopy, sub-canopy, and understory trees. Less prevalent deciduous and conifer species were also retained. Five treatments were implemented: control; thinning with scattered slash and supplemental downed wood; thinning with scattered slash and clumped supplemental downed wood; thinning with piled slash and clumped supplemental downed wood; and thinning with scattered slash and no supplemental downed wood. Thinning was augmented by 0.1-acre clearcut gaps totaling 10 percent of the area, and 0.8- to 1.5-acre skips totaling 25 percent of the area where no entry was allowed. Gap sizes were intended to simulate those found in old-growth forests, and skips were frequently located to protect existing snags.
- *Status*: Pre-treatment measurements were taken from 1995 to 1998 (including density, diameter, height, basal area, and volume by tree species in each of three strata, cover of shrubs, ferns, herbs, mosses, lichens, and downed wood) in all eight blocks. One 3.5-acre stem-mapped plot was measured per block. Four blocks were thinned in 1997-99. Post-treatment measurements (same as pre-treatment) were taken on the four thinned blocks. Two blocks have had some downed wood treatments. Monitoring will continue for tree growth and yield, understory plant development, use by small mammals, fungal communities, flying squirrels, and amphibians.
- *Results.* The prescription was operationally feasible. Any trees less than six inches in diameter were cut. Cascara was knocked down during thinning, but has since resprouted. There was little damage from the thinning operation to remaining trees. Windthrow occurred but appeared to be unrelated to the treatments (note: windthrow is a large problem in this region). After five years, individual trees in the thinned area are growing faster than those in the skips. Some gaps have a carpet of hemlock. Further treatments will be base on future monitoring results; treatments may include overstory or understory tree thinning.

Multiple-Objective Thinning on the Olympic National Forest. This project is being implemented by the USFS in compliance with the 1994 Northwest Forest Plan (NWFP) (http://www.fs.fed.us/r6/olympic).

- *Goals:* The multiple-objective commercial thinning program is intended to accelerate the process of late-successional forest development by creating conditions that encourage the growth of a diverse understory and complex forest structure that enhances biological diversity.
- *Sites:* Throughout second-growth forests in Late-Successional Reserves (LSRs) and AMAs in the ONF on the Olympic Peninsula in western Washington.
- *Methods:* The project utilizes contemporary thinning prescriptions including variable density thinning, gaps and skips, and maintaining and creating snags and downed wood. Thinning prescriptions generally call for the removal of some of the trees within a certain size range (e.g., 6 to 20 inches diameter at breast height (dbh)) to release the dominant cohort and smaller understory trees (e.g., less than 6 inches dbh), allowing them all to grow more quickly. The upper limit of the cut range is based on the diameters of the dominant trees in the stand, and the desired post-thinning conditions. A post-thinning relative density target of 30 to 40 (see Section 5.3 for explanation) is generally used, except where windthrow is a serious concern or western hemlock is the predominant species, in which case the treatment is based on the removal of approximately one-third of the stand's basal area. Deciduous species, minor conifer species, and damaged and diseased trees are retained to enhance species diversity. Efforts are also made to protect existing understory plants. Techniques to minimize soil compaction and erosion include the use of designated skid trails, narrow cable corridors (e.g., 8 to 10 feet), and partial or full elevation of logs off the ground when using skyline cable yarding systems. Where cut-to-length processors are used to fell and stack trees, they are restricted to the designated skid trails and one 'ghost trail' pass between skid trails as necessary to reach all the trees to be cut. The heavier forwarder must remain on the skid trails.
- *Status:* Currently, thinnings on the ONF are proceeding on a stand-by-stand basis, with interest in developing a comprehensive landscape-based thinning program. Although most thinnings have been conducted in AMAs, the goal of the project is to thin all of the LSRs before they reach 80 years old.
- *Results:* Numerous examples of commercial thinnings took place on the ONF prior to the NWFP provide clues about how thinned areas may develop over time. A site thinned ten years ago where understory plants were retained during thinning operations currently exhibits a well-developed, multi-species understory, with high relative vertical diversity. Another stand, thinned from below in 1978 to roughly 80 trees per acre, currently exhibits a well-developed, multiple-species understory and a diverse undergrowth component. A third stand, also thinned from below with some removal of dominant trees, now contains a well-developed understory of western hemlock, western red cedar, and rhododendron under a Douglas-fir overstory.

Silvicultural Options for Harvesting Young-Growth Production Forests. The principal investigators of this project are David Marshall (USFS), Robert Curtis (USFS), Dean DeBell (USFS), and Jeffrey DeBell (WADNR), with the PNW, WDNR, UW, and the University of Idaho (UI) as cooperating organizations (http://www.fs.fed.us/pnw/olympia/silv/selected_studies/blue_ridge/blueridge_poster.htm).

- *Goals:* The objectives of this study are to evaluate forestry practices and silvicultural systems that can be used to reduce visual impacts of harvesting operations while maintaining a productive forest for future generations. Results will provide managers with data on a range of contrasting silvicultural systems and quantitative information about public response, economic performance, and biological responses of the treatments.
- *Sites:* On 30- to 75-acre plots, replicated at 3 different sites, on the Capitol State Forest in the Puget lowlands in western Washington.
- *Methods*: This study involves six randomly assigned treatments plus controls: 1) clearcut; 2) retained overstory (approximately 15 trees per acre); 3) small patch cutting (clearcut 1.5- to 5.0-acre patches with 20 percent harvested every 15 years); 4) group selection (clearcut groups of trees less than 1.5-acre with thinning every 15 years to maintain the same average basal area as the patch cutting treatment); 5) extended rotation with commercial thinning (repeated thinnings to maintain high growth rates until deferred clearcut); and, 6) extended rotation without thinning (deferred clearcut harvest). All open areas greater than 0.1 acres are planted.
- *Status*: The first replication was installed during the summer of 1998 in a 69-year-old, naturally regenerated site class II (see Section 5.3 for definition) Douglas-fir stand. The second replication of the study was harvested during the summer of 2002 using a cable thinning system. The third replication will be harvested during the summer of 2004. The B.C. Ministry of Forests Research Branch installed a study during 2002 on Vancouver Island near Campbell River, called the Silvicultural Treatments for Ecosystem Management (STEMS) project. The same treatments, plot design, and measurements were used, plus one additional aggregated variable retention treatment was added.
- *Results*: No results are currently available.

Forest Ecosystem Study. The principal investigators for this project are Andy Carey, David Thysell, and Angus Brodie of the PNW-USFS (USFS PNW-GTR-457, 1999).

- *Goals:* To address the development of spotted owl habitat and enhance biodiversity through experimental manipulation of managed areas.
- *Sites:* On two stands of approximately 514 acres on the Fort Lewis Military Reservation in the Puget lowlands of western Washington. One stand was clearcut in 1925 and had two commercial thinnings prior to the study. The second stand was clearcut in 1937 with no previous thinning.
- *Methods:* The study uses a randomized block experimental design, with two blocks per stand. Each block was divided into four 19.4-acre treatment areas to include: 1) a control; 2) variable density thinning with underplanting; 3) flying squirrel den

augmentation with no thinning; and, 4) flying squirrel den augmentation with variable density thinning and underplanting. Thinning was implemented at three intensities in 49 0.4-acre grid cells in corresponding treatment areas: 1) a light thin (thin trees greater than 8 inches dbh to 125 trees per acre); 2) a heavy thin (thin trees greater than 8 inches dbh to 75 trees per acre); and, 3) a root rot thin (remove trees from root rot pockets and thin trees greater than 8 inches dbh to 16 trees per acre). All thins were thinning from below, removing suppressed and subdominant trees. Deciduous trees, shrubs, and all snags greater than 12 inches dbh were retained. Planting was done in heavy and root rot thin treatments, using red alder (*Alnus rubra*), western redcedar (*Thuja plicata*), western white pine (*Pinus monticola*), and grand fir (*Abies grandis*) at a density of 206 trees per acre. Flying squirrel den augmentation has done by installing 24 nestboxes, creating 16 cavities, and inoculating six trees with decay fungi per treatment block. Two or more thinning entries are planned in the future, likely ten years apart.

- *Status:* Baseline monitoring of vegetation, downed wood, small mammals, arboreal rodents, and owls was conducted in 1991-1992. Cavities and nest boxes were installed in 1992, variable density thinning occurred in 1993, and planting was done in 1994. Post-treatment monitoring includes live trees, snags, downed wood, understory vegetation (shrubs and herbs), soil food webs (fungal, mycelia, bacteria, and nematodes), epigeous and hypogeous fungi, arboreal and forest floor mammals, and winter birds. Study sites will be protected from further management for a minimum of 20 years.
- *Results:* Specific cell-by-cell thinning target tree densities were not always reached, but the overall goal of creating a mosaic of variably stocked cells while retaining wind firmness was achieved, with little windthrow occurring even during a severe storm event in 1995. Soil food webs appear resilient to active timber management, although past management does appear to have reduced fungal dominance. Mechanical disturbance during thinning appeared to destroy fungal mats, but impacts on truffle production were brief, and the heterogeneity created by thinning increased sporocarp diversity to a richness that approximates old-growth forest. Past commercial thinning produced stands with understories dominated by clonal natives with numerous exotics present, few shade-tolerant understory trees, and little spatial heterogeneity. Unthinned stands had depauperate understories and low abundances of small mammals and winter birds. Five years after thinning there was increased diversity and abundance of native understory plants, with an ephemeral increase in exotics. Planting is leading to increased spatial heterogeneity. Thinning also had positive affects on forest floor mammals and winter birds. Some arboreal mammals increased, while flying squirrels (initially rare) showed a brief decline, but remain rare. Use of supplemental nest boxes and created cavities increased steadily after installation. By 1995, 80 percent of all nest boxes exhibited use.

The Young Stand Thinning and Diversity Study. This study is being implemented by the Cascade Center for Ecosystem Management, an interdisciplinary team from the PNW-USFS and the Oregon State University College of Forestry (http://www.fsl.orst.edu/ccem/yst/ystd.html).

- *Goals:* The goal of this study is to determine if different thinning, underplanting, and snag creation treatments can accelerate the development of late-successional habitat in 35 to 50 year-old plantations. A primary objective is to better understand how to provide wood fiber while enhancing diversity. The study will assess treatment effects on stand growth and mortality, understory plants (shrubs, herbs, bryophytes), dead wood, chanterelle productivity, small mammal, amphibian, and diurnal songbird abundance and diversity, arthropods, planning and layout costs, thinning costs, soil disturbance, nutrient cycling, and special forest products.
- *Sites:* The study encompasses approximately 1,200 acres, with 16 Douglas-fir stands averaging 74 acres each. Study sites were located on three ranger districts of the Willamette National Forest, in the western Oregon Cascades, and originated from clearcut harvesting 35 to 42 years prior to study initiation in 1991.
- *Methods:* There are four replications of four stand treatments: 1) control (which had about 250 trees per acre); 2) light thin (to 100-110 trees per acre); 3) heavy thin (to 50-55 trees per acre) with underplanting; and, 4) light thin with gaps and underplanting (to 100-110 trees per acre, with two 0.5-acre gaps every five acres). When light thin stands reach a relative density (RD) of 50, they will be thinned to RD 30, with thins expected every 15 to 20 years. Gaps will be precommercially thinned, with the stands maintained at 20 percent gaps. Heavy thins will be thinned to RD 20 when the overstory reaches RD 50, with thins expected every 25 to 30 years. One pre-commercial thin is expected in the understory. Three types of thinning systems will be compared: tractor, cable, and mechanical (harvester/forwarder). All treatments will retain deciduous species. It was proposed to create one snag per acre, with a minimum of 12 inoculated and 12 topped trees per stand.
- *Status:* Baseline data was collected from 1991 to 1994. Thinning took place from 1994 to 1996. One- and three-year post-treatment data have been collected. Snag creation was anticipated to occur in 2001. Permanent vegetation plots (0.25 acres) have been established. It is hoped that the study will continue indefinitely.
- *Results:* Post-treatment residual tree densities averaged 251 trees per acre for the control, 60 trees per acre for the heavy thin, 106 trees per acre for the light thin, and 86 trees per acre for light thin with gaps. Three years post-treatment, bryophyte ground cover (mosses) had no significant treatment effects but was positively correlated with overstory cover. Herb cover was significantly greater in heavy thin and light thin with gap treatments than controls. Short shrubs showed no response and tall shrubs appear to have been set back by thinning damage. Productivity of chanterelle mushrooms declined after treatment, and did not rebound after three years. Thinning had few detectable impacts on small mammals and amphibians, with no species eliminated as a result of the treatment. Deer mouse and ensatina populations increased in the light thin and light thin with gaps treamments, but not in the heavy thin treatment. Trowbridges's shrew decreased in the heavy thin treatment. Bird species richness and diversity increased in all three thinning treatments, with several uncommon bird species present in thinning stand that were absent or nearly so prior to treatment.

New skid trails covered 26-29 percent of the harvested portion of the stand. Harvester and forwarder traffic was found to increase bulk density (a measure of compaction) an average of 11 to 12 percent on undisturbed soil, but there was no evidence that this traffic increased bulk density on old skid trails. Planning and layout costs did not differ between treatments. The mechanized system had the lowest contractor layout costs, followed by the tractor systems, and the skyline system had the highest costs.

Density Management Studies. These studies are being implemented by the U.S. Bureau of Land Management (BLM) in western Oregon (http://ocid.nacse.org/nbii/density/overview.html).

- *Goals:* Determine whether density management treatments result in differences in stand structural characteristics and species diversity. Evaluate the response of various plant and animal taxa to density management. Develop stand-level density management treatments that may accelerate late-successional habitat development while producing wood for the regional economy.
- *Sites:* Seven sites were selected in 40 to 70 year-old Douglas-fir forests on BLM land in western Oregon (in both the Cascade and Oregon Coast Range). Sites are a minimum of 50 acres in size.
- *Methods:* Four treatments were designed: 1) control (200 to 350 trees per acre); 2) high density retention (70 to 75 percent of area thinned to 120 trees per acre, 20 to 30 percent of area unthinned riparian reserves or leave islands); 3) moderate density retention (60 to 65 percent of area thinned to 80 trees per acre, 20 to 30 percent of area in unthinned riparian reserves or leave islands, and 10 percent of area in circular patch openings); and 4) variable density retention (10 percent of area thinned to 40 trees per acre, 25 to 30 percent of area thinned to 80 trees per acre, 25 to 30 percent of area thinned to 120 trees per acre, 20 to 30 percent of area in unthinned riparian reserves or leave islands, and 10 percent in circular patch openings). Within the control, high density, and moderate density treatments, nine 1-acre areas were underplanted with western hemlock and western red cedar trees. Western hemlock, Douglas-fir, western red cedar, and grand fir trees were planted in all patch openings and in the 40 trees per acre areas of the variable density treatment.
- *Status:* Harvesting was 95 percent complete in 2001. Permanent vegetation monitoring plots (0.25 acre) are being installed. Monitoring of stand and vascular plant species development will occur within two years of treatment and then periodically for about 30 years. Plot data will address overstory tree response to density management, snag recruitment, large and small downed wood recruitment and dynamics, shrub and herb dynamics under density management, tree regeneration (planted and natural regeneration), and presence of vascular plant species closely associated with late-successional or old-growth forests within the range of the northern spotted owl.
- *Results:* No results are available.

Experimental Gap Study. The principal investigators of this study are Tom Spies (PNW-USFS, OSU), Jerry Franklin (UW), and Andrew Gray (PNW-USFS) (http://www.fsl.orst.edu/lter/data/abstractdetail.cfm?dbcode=TV025&topnav=135, http://www.fs.fed.us/pnw/sciencef/scifi43.pdf, http://outreach.cof.orst.edu/silvopt/posters/Grayab.htm).

- *Goals:* 1) To examine the long-term response of overstory and understory trees to creation of canopy gaps in mature Douglas-fir/western hemlock forests in the Cascade Range. 2) To uncover the role of gaps in creating forest diversity, their different effects on multi-layered old-growth forests and single-layer mature forests, and their effects on below ground ecosystem attributes such as root density, soil moisture and nutrient cycling. 3) To discover if gaps facilitate the development of late-successional forests.
- *Sites:* Four stands were used, three in the Wind River Experimental Forest in the south-central Washington Cascades and one in the H.J. Andrews Experimental Forest in the western Oregon Cascades. Two stands were old-growth forest (approximately 500 years old), and two stands were naturally regenerated mature forest (88 and 130 years).
- *Methods:* Two circular gaps in each of four sizes (diameters of 0.2, 0.4, 0.6, and 1.0 times the canopy height) and controls were established in each of the four stands (totaling 32 gaps and 8 controls). The largest gaps were 0.5 acre. Overstory trees within 40 to 80 feet of gap edges were mapped and their diameters measured before gap creation and again seven years later. A subsample of trees were cored to quantify growth before and after gap creation. Overstory tree mortality was evaluated annually. Processes studied included tree establishment, survival, and growth, and understory vegetation cover within and surrounding gaps. Solar radiation, air and soil temperature, and soil moisture were also measured. Litter input, decomposition, root density, N-mineralization and N-leaching, soil microbial response and mycorrhizal mats, understory herbs and shrubs, composition and abundance of small mammal communities have also been studied at the sites.
- *Status:* The gaps were created in 1990, with various studies ongoing. This is intended to be long-term study, so sites are protected.
- *Results:* As of 2002, 18 journal articles, theses, and dissertations have been published that address findings from this study (see list at websites above). Key findings include: 1) adjacent old-growth trees had a greater growth response to gap formation (137 percent of pre-gap growth rates) than mature trees (114 percent), and adjacent tree growth increased with gap size; 2) Douglas-fir and other conifer trees can successfully regenerate in a wide range of gap sizes, although Douglas-fir had more success in gaps larger than 1/3 acre; 3) growth of intermediate, shade-tolerant trees tended to be greater on north sides of small gaps than on south sides, with the reverse true for large gaps (e.g., the southern portions of the gaps were more shaded); 4) seedling size increased with gap size and was greatest at gap centers; 5) Douglas-fir growth was relatively low except in the largest gaps while western hemlock growth increased dramatically with gap size and Pacific silver fir (*Abies amabilis*) growth responded least to gap size; 6) below ground gaps are created by all above ground

gaps; 7) higher temperature and increased moisture in gaps leads to increased decomposition rates and higher nutrient availability, boosting the productivity of the surrounding forest; 8) soil moisture in gaps varies with distance from gap edge and orientation with gap centers usually wetter than gap edges, which are wetter than surrounding forest; 9) plant species diversity was higher in gaps than in closed-canopy forest, with some weedy species but also many native species; and, 10) gaps can remain devoid of tree saplings for as much as 50 years after formation. Lack of seeds may mean that planting becomes a necessity in created gaps.

Response to Commercial Thinning in Older (110 years) Douglas-fir Forests. This study was published in 1982 by Richard Williamson (USFS Research Paper PNW-296).

- *Goal:* Investigate the merits of commercially thinning older stands.
- *Sites:* A 70-acre site of 110-year-old Douglas-fir forest on the Wind River Experimental Forest, Wind River District of the Gifford Pinchot National Forest, in the south central Washington Cascades.
- *Methods:* A randomized block design was used testing a control and two treatments (a light thinning, where approximately 20 percent of the volume was cut, and heavy thinning, with 25 to 33 percent of the volume cut). Each treatment was replicated three times. Stands were sampled 19 years after thinning. Because of the wide range in site index among plots and stocking differences, results were tested by comparing response ratios of gross volume growth to normal gross growth for the same site index (e.g., ratios of volume-growth percentages of treated plots relative to control, adjusted for differences in site index and stocking). Increases could result from either the removal of slow-growing trees in thinning or an actual increase in growth rate of residual trees, or both. Individual trees were also compared.
- *Status:* The study is complete.
- *Results:* Gross growth of the heavily thinned plots was 27 percent better than expected if growth were directly proportional to growing stock. Lightly thinned stands had no difference in gross growth compared to controls. Lightly thinned stands averaged 119 percent of normal net growth and heavily thinned stands averaged 136 percent, with unthinned stands averaging much less than normal. Average mortality on control plots was five times the mortality on heavily thinned plots and three time that on lightly thinned plots. Individual tree responses showed a 30 percent greater growth than controls in the heavily thinned stands, and eight percent greater in the lightly thinned stands. The relative response of suppressed trees in the heavily thinned stands was almost double the control, with codominant and intermediate trees with 112 and 108 percent respectively. Dominant trees had a gain of 30 percent. This study indicated that older trees can respond positively to thinning.

Very Young Stand Management, an Adaptive Management Case Study. The principal investigators of this study are Connie Harrington (PNW-USFS), Jim Mayo (USFS), and John Cissel (USFS) through the Cascade Center for Ecosystem Management (http://www.fsl.orst.edu/ccem/pdf/veryyss.pdf).

- *Goals:* 1) Demonstrate options and improve understanding of alternative approaches to precommercial thinning. 2) Produce forest stands that differ in species composition and structural components; monitor short and long-term plant responses. 3) Accelerate development of late-successional forest characteristics in some treatments. 4) Determine effects on forest growth and yield.
- *Sites:* Study plots are located on the Willamette National Forest, in the western Oregon Cascades, and are at least 15 acres in size.
- *Methods:* The study design utilizes a control and four treatments. The control will be thinned to 8-foot spacing (680 trees per acre). The treatments will include: 1) thin to 12-foot spacing (300 trees per acre); 2) thin to 12-foot spacing with 8 uniformly distributed 0.05-acre gaps per acre and interplanting with shade-tolerant conifer and deciduous species; 3) thin to 12-foot spacing with 0.02-, 0.04-, and 0.05-acre gaps; and, 4) thin to 12-foot spacing with 0.02-, 0.04- and 0.05-acre gaps and interplanting with shade-tolerant conifer and deciduous species. Monitored response variables will include ecological and economic measures such as stand structure, plant composition, and tree growth. Costs and values of treatments will be compared. If funding becomes available, sampling of small mammals, amphibians, and birds will be conducted.
- *Status:* Five plots have been established.
- *Results:* No results are currently available.

Alternative Silvicultural Treatments for Young Plantations in the Pacific Northwest. The principal investigators for this study are Connie Harrington, Dean DeBell, and Leslie Brodie through (PNW-USFS) (http://www.fs.fed.us/pnw/olympia/silv/selected_studies/clearwater/alternative_poster.htm).

- *Goals:* Increase diversity in stand structure and species composition in young stands.
- *Sites:* Plots are in 10 to 13 year-old stands. The oldest installation is on the Mt. St. Helens National Volcanic Monument in western Washington, where five plots (each 16 acres) of each treatment were installed in 1994-5. Other installations of this trial have been established near Blue River in the Oregon Cascades (one), and Forks on the Olympic Peninsula (five).
- *Methods:* Four treatment levels were implemented in the study with controls. The treatments include: 1) uniform thinning; 2) uniform thinning and planting other species in small uniform openings (about 0.04 acre); 3) irregular thinning with variable sized gaps; and, 4) irregular thinning with variable sized gaps and planting other species. The treatments will require multiple entries to meet their goals. Tree growth, stand structure, and understory plant composition and cover are being monitored.
- *Status*: All plots have been treated and sampled from two and five years post-thinning.

- *Results:* The control treatment had a lower percentage of trees in the larger diameter classes. Cover of herbaceous plants (2 and 5 years after thinning) decreased in the control and increased with thinning and gap creation.

Numerous other smaller projects that include thinning and planting for heterogeneity and biodiversity, or have components that may be applicable to restoration in the CRMW, have also been started since 1990. In particular, the Department of Forest Science at Oregon State University and its Cooperative Forest Ecosystem Research (CFER) program have several ongoing thinning projects in the Oregon Cascades and Oregon Coast Range, many of which include wildlife responses to thinning (see: www.fsl.orst.edu and www.fsl.orst.edu/cfer). A long-term interdisciplinary study of the ecological effects of regeneration harvest with alternative levels and patterns of canopy retention focuses primarily on shelterwood treatments, but does include one 75 percent aggregated retention treatment that may be applicable to the CRMW (Franklin et al. 1999). Although these projects are not included in the summary above, we will continue to monitor them as data become available.

We have also reviewed restoration projects that have similar goals, but that are not directly applicable to upland forest restoration in the CRMW. An example is the recent plan for the Klamath Tribe's management of the reservation pine forest in Oregon (Johnson et al. 2003). This plan advocates active management to restore forest complexity and big game habitat. Methods recommended include prescribed fire, mechanical thinning, planting, mowing, and other silvicultural manipulations.

The long history of commercial forestry in the Pacific Northwest has taught us much about thinning to grow big trees faster. In addition to maximizing tree growth, commercial thinning may also have some positive influences on other organisms and forest structure. A retrospective study comparing commercially thinned areas, unthinned areas, and old-growth in western Oregon found that 32 areas commercially thinned 10 to 20 years previously had greater herb species richness, greater density of conifer seedlings, and greater density of both tall and short shrubs than unthinned areas (Muir et al. 2002). Standard commercial thinning creates uniformity in overstory tree size and spacing, however, and a late successional forest consists of much more than large uniform trees.

Appendix B. List of wildlife species potentially occurring in the CRMW. Asterisks denote CRW-HCP species of concern.

			Habitat Association[1]									Habitat Elements[1]										
			Forest Stage						Aquatic													
Group	Common Name	Scientific Name	Open	Hardwood	Mixed	Young	Mature	Old-growth	Rivers, Streams	Wetlands/Riparian	Lakes, Ponds	Canopy Layers	Downed Wood	Snags	Tree Cavities	Hollow Trees	Large Branches	Mistletoe	Shrubs, Forbs, Grasses	Edges	Rocks/Talus	other
Invertebrates (incomplete list)																						
Insects	Beller's Ground Beetle*	*Agonum belleri*								X	X											spagnum bogs, <3000'
	Carabid Beetle*	*Bembidion gordoni*							X													gravel bars
	Carabid Beetle*	*Bembidion stillaquamish*							X													gravel bars
	Carabid Beetle*	*Bembidion viator*								X												swamps, bogs, low elevation
	Carabid Beetle*	*Bradycellus fenderi*							X	X												low elevation
	Carabid Beetle*	*Nebria gebleri cascadensis*							X													
	Carabid Beetle*	*Nebria kincaidi balli*							X													high elevation
	Carabid Beetle*	*Nebria paradisi*							X													high elevation
	Carabid Beetle*	*Omus dejeanii*		X	X	X	X	X	X	X												
	Carabid Beetle*	*Pterostichus johnsoni*							X													
	Fender's Soliperan Stonefly*	*Soliperla fenderi*							X													
	Hatch's Click Beetle*	*Eanus hatchii*								X	X											spagnum bogs
	Johnson's (Mistletoe) Hairstreak*	*Mitoura johnsoni*				X	X	X										X				
	Long-horned Leaf Beetle*	*Donacia idola*								X	X											spagnum bogs
Mollusks	Blue-gray Taildropper*	*Prophysaon coeruleum*					X	X					X									moist
	Oregon Megomphix*	*Megomphix hemphilla*					X	X					X									
	Papillose Taildropper*	*Prophysaon dubium*					X	X		X			X								X	moist
	Puget Oregonian*	*Cryptomastix devia*		X			X	X		X			X								X	moist
	Snail*	*Valvata mergella*									X											low elevation
Fish (27 species)																						
Lampreys	River Lamprey*	*Lampetra ayresi*							X													
	Western Brook Lamprey	*Lampetra richardsoni*							X													
	Pacific Lamprey*	*Lampetra tridentata*							X													
Salmonids	Pygmy Whitefish*	*Prosopium coulteri*							X		X											
	Mountain Whitefish	*Prosopium williamsoni*							X		X											
	Coastal Cutthroat Trout, Sea-Run*	*Oncorhynchus clarki clarki*							X													anadromous
	Coho Salmon*	*Oncorhynchus kisutch*							X													anadromous
	Rainbow Trout	*Oncorhynchus mykiss*							X		X											
	Steelhead Trout*	*Oncorhynchus mykiss*							X													anadromous
	Sockeye Salmon*	*Oncorhynchus nerka*							X													anadromous
	Kokanee*	*Oncorhynchus nerka*							X		X											
	Chinook Salmon*	*Oncorhynchus tshawytscha*							X													anadromous
	Dolly Varden	*Salvelinus malma*							X													anadromous
	Bull Trout*	*Salvelinus confluentus*							X		X											

			Habitat Association[1]									Habitat Elements[1]										
			Forest Stage						Aquatic													
Group	**Common Name**	**Scientific Name**	Open	Hardwood	Mixed	Young	Mature	Old-growth	Rivers, Streams	Wetlands/Riparian	Lakes, Ponds	Canopy Layers	Downed Wood	Snags	Tree Cavities	Hollow Trees	Large Branches	Mistletoe	Shrubs, Forbs, Grasses	Edges	Rocks/Talus	**other**
Minnows	Peamouth	*Mylocheilus caurinus*							X		X											
	Northern Pikeminnow	*Ptycheilus oregonensis*							X		X											
	Longnose Dace	*Rhinichthys cataractae*							X		X											
	Speckled Dace	*Rhinichthys osculus*							X													
	Redside Shiner	*Richardsonius balteatus*							X		X											
Suckers	Longnose Sucker	*Catostomus catostomus*							X		X											
	Largescale Sucker	*Catostomus macrocheilus*							X		X											
Sticklebacks	Threespine Stickleback	*Gasterosteus aculeatus*							X		X											
Sunfishes	Large-mouth Bass	*Micropterus salmoides*							X		X											
Perches	Yellow Perch	*Perca flavescens*									X											
Sculpins	Torrent Sculpin	*Cottus rhotheus*							X													
	Riffle Sculpin	*Cottus gulosus*							X													
	Shorthead Sculpin	*Cottus confusus*							X													
	Coastrange Sculpin	*Cottus aleuticus*							X													
	Prickly Sculpin	*Cottus asper*							X													
Amphibians (16 species)																						
Salamanders	Northwestern Salamander*	*Ambystoma gracile*		X	X	X	X	X	X	X	X		X							X	X	
	Long-toed Salamander*	*Ambystoma macrodactylum*		X	X	X	X	X	X	X	X		X							X	X	
	Cascade Torrent Salamander*	*Rhyacotriton cascadae*					X	X	X	X			X						X			seeps, headwater streams
	Larch Mountain Salamander*	*Plethodon larselli*					X	X					X	X							X	caves
	Van Dyke's Salamander*	*Plethodon vandykei*					X	X	X				X								X	caves, waterfalls, small streams
	Pacific Giant Salamander*	*Dicamptodon tenebrosus*					X	X	X	X	X		X								X	
	Ensatina	*Ensatina eschscholtzii*	X	X	X	X	X	X					X	X								
	Western Redback Salamander*	*Plethodon vehiculum*	X	X	X	X	X	X					X								X	<3600'
	Roughskin Newt*	*Taricha granulosa*	X	X	X	X	X	X	X	X	X		X						X	X		
Frogs/Toads	Western Toad*	*Bufo boreas*	X	X	X	X	X	X	X	X	X		X									moist
	Pacific Treefrog	*Pseudacris regilla*	X	X	X	X	X	X	X	X	X											
	Tailed Frog*	*Ascaphus truei*		X	X	X	X	X	X			X	X						X	X	X	headwater streams
	Northern Red-legged Frog*	*Rana aurora aurora*		X	X	X	X	X	X	X	X		X									
	Cascades Frog*	*Rana cascadae*		X	X	X	X	X		X	X		X									>1600'
	Oregon Spotted Frog*	*Rana pretiosa*							X	X	X								X			
	Bullfrog	*Rana catesbeiana*							X	X	X											
Reptiles (7 species)																						
Turtles	Western Pond Turtle*	*Clemmys marmorata*							X	X	X									X		<1000', litter
Lizards	Northern Alligator Lizard	*Elgaria coerulea*	X																	X	X	
	Western Fence Lizard	*Sceloporus occidentalis*	X										X							X	X	
Snakes	Rubber Boa	*Charina bottae*	X	X	X	X	X	X		X			X								X	burrows

Group	Common Name	Scientific Name	Habitat Association[1]									Habitat Elements[1]										
			Forest Stage						Aquatic													
			Open	Hardwood	Mixed	Young	Mature	Old-growth	Rivers, Streams	Wetlands/Riparian	Lakes, Ponds	Canopy Layers	Downed Wood	Snags	Tree Cavities	Hollow Trees	Large Branches	Mistletoe	Shrubs, Forbs, Grasses	Edges	Rocks/Talus	other
	Western Terrestrial Garter Snake	*Thamnophis elegans*	X	X	X	X	X	X	X	X	X											burrows
	Northwestern Garter Snake	*Thamnophis ordinoides*	X	X	X	X	X	X														burrows
	Common Garter Snake	*Thamnophis sirtalis*	X	X	X	X	X	X	X	X	X								X			burrows
Birds (145 species)																						
Loons	Common Loon*	*Gavia immer*							X		X								X			
Grebes	Pied-bill Grebe	*Podilymbus podiceps*							X	X	X								X			
	Horned Grebe	*Podiceps auritus*							X	X	X											
	Red-necked Grebe	*Podiceps grisegena*							X	X	X											
	Eared Grebe	*Podiceps nigricollis*							X	X	X											
	Western Grebe	*Aechmophorus occidentalis*							X	X	X											
Cormorants	Double-crested Cormorant	*Phalacrocorax auritus*							X		X											
Herons	Great Blue Heron*	*Ardea herodias*	X	X	X		X	X	X	X	X			X					X	X		
	Green Heron	*Butorides virescens*		X	X	X	X	X	X	X	X								X			
Swans	Trumpeter Swan	*Cygnus buccinator*							X	X	X								X			
Geese	Canada Goose	*Branta canadensis*	X						X	X	X								X			
Ducks	Wood Duck	*Aix sponsa*					X	X	X	X	X			X	X							
	Mallard	*Anas platyrhynchos*	X						X	X	X								X	X		
	Cinnamon Teal	*Anas cyanoptera*	X						X		X								X	X		
	Harlequin Duck*	*Histrionicus histrionicus*					X	X	X		X		X		X				X	X		
	Common Goldeneye	*Bucephala clangula*					X	X	X		X			X	X					X		
	Bufflehead	*Bucephala albeola*					X	X	X	X	X			X	X					X		
	Hooded Merganser	*Lophodytes cucullatus*					X	X	X	X	X			X	X					X		
	Common Merganser	*Mergus merganser*					X	X	X		X			X	X	X				X		
	Gadwall	*Anas strepera*	X						X	X	X									X		
	Green-winged Teal	*Anas crecca*	X						X	X	X									X		
	American Wigeon	*Anas americana*	X						X	X	X									X		
	Northern Pintail	*Anas acuta*	X						X	X	X									X		
	Northern Shoveler	*Anas clypeata*	X						X	X	X									X		
	Ruddy Duck	*Oxyura jamaicensis*							X	X	X								X			
	Canvasback	*Aythya valisineria*							X	X	X								X			
	Ring-necked Duck	*Aythya collaris*							X	X	X											
	Greater Scaup	*Aythya marila*							X		X											
	Lesser Scaup	*Aythya affinis*							X	X	X											
Coots	American Coot	*Fulica americana*							X	X	X								X	X		
Plovers/ Sandpipers	Killdeer	*Charadrius vociferus*	X						X	X	X								X	X	X	
	Spotted Sandpiper	*Actitis macularia*	X						X	X	X								X		X	
	Common Snipe	*Gallinago gallinago*	X						X	X	X											

Group	Common Name	Scientific Name	Habitat Association[1]									Habitat Elements[1]										
			Forest Stage						Aquatic													
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Alcids	Marbled Murrelet*	*Brachyrhamphus marmoratus*					X	X									X	X				moss
Vultures	Turkey Vulture	*Cathartes aura*				X	X	X					X	X	X	X					X	cliffs, caves
Hawks	Osprey*	*Pandion haliaeetus*					X	X	X		X	X		X						X		
	Bald Eagle*	*Haliaeetus leucocephalus*					X	X	X	X	X	X		X						X		
	Golden Eagle*	*Aquila chrysaetos*	X				X	X						X					X	X	X	cliffs
	Sharp-shinned Hawk	*Accipiter striatus*			X	X	X			X		X								X		
	Cooper's Hawk	*Accipiter cooperii*		X	X	X	X	X		X		X								X		
	Northern Goshawk*	*Accipiter gentilis*		X	X		X	X		X			X	X				X	X	X		tree deformities
	Red-tailed Hawk	*Buteo jamaicensis*	X	X	X	X	X	X						X				X	X	X	X	cliffs
Falcons	American Kestrel	*Falco sparverius*	X		X	X	X	X						X	X					X	X	
	Merlin*	*Falco columbarius*	X							X					X				X	X		cliffs, high elevation
	Peregrine Falcon*	*Falco peregrinus*	X				X	X	X	X	X	X		X						X		cliffs
Grouse/Quail	Blue Grouse	*Dendragapus obscurus*	X				X	X	X	X			X					X	X		X	springs
	Ruffed Grouse	*Bonasa umbellus*	X		X	X			X	X			X						X		X	springs
	California Quail	*Callipepla californica*	X			X													X	X		
	Mountain Quail	*Oreortyx pictus*	X																X	X		
Pigeons	Band-tailed Pigeon*	*Columba fasciata*	X	X	X	X	X	X	X			X							X		X	mineral springs, berry-producing shrubs
Owls	Western Screech Owl	*Otus kennicottii*		X	X	X	X	X		X				X	X							
	Great Horned Owl	*Bubo virginianus*	X	X	X	X	X	X						X	X	X		X		X	X	caves, cliffs
	Northern Pygmy Owl	*Glaucidium gnoma*		X	X	X	X	X						X	X							
	Northern Spotted Owl*	*Strix occidentalis caurina*					X	X				X	X	X	X	X	X	X				flying squirrels
	Barred Owl	*Strix varia*		X	X	X	X	X	X	X				X	X	X		X				
	Northern Saw-whet Owl	*Aegolius acadicus*			X	X	X	X		X				X	X							
Nightjars	Common Nighthawk	*Chordeiles minor*	X																		X	
Swifts	Black Swift*	*Cypseloides niger*			X		X	X	X												X	cliffs, caves
	Vaux's Swift*	*Chaetura vauxi*					X	X				X		X	X	X						insects
Hummingbirds	Rufous Hummingbird*	*Selasphorus rufus*	X							X									X	X		flowers
Kingfisher	Belted Kingfisher	*Ceryle alcyon*							X		X											burrows
Woodpeckers	Red-breasted Sapsucker	*Sphyrapicus ruber*		X	X	X	X	X				X		X	X							
	Downy Woodpecker	*Picoides pubescens*		X	X	X	X	X				X		X	X							
	Hairy Woodpecker	*Picoides villosus*		X	X	X	X	X				X		X	X							
	Northern Flicker	*Colaptes auratus*		X	X	X	X	X						X	X	X				X		
	Pileated Woodpecker*	*Dryocopus pileatus*	X	X	X	X	X	X				X	X	X	X	X						insects
	Three-toed Woodpecker*	*Picoides tridactylus*	X	X	X	X	X	X				X		X	X							insects, high elevation
Flycatchers	Olive-sided Flycatcher*	*Contopus cooperi*	X	X	X	X	X	X		X		X		X						X		emergent trees
	Western Wood Pewee	*Contopus sordidulus*	X			X				X										X		
	Willow Flycatcher*	*Empidonax traillii*	X							X									X			

			Habitat Association[1]									Habitat Elements[1]										
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Group	**Common Name**	**Scientific Name**	Open	Hardwood	Mixed	Young	Mature	Old-growth	Rivers, Streams	Wetlands/Riparian	Lakes, Ponds	Canopy Layers	Downed Wood	Snags	Tree Cavities	Hollow Trees	Large Branches	Mistletoe	Shrubs, Forbs, Grasses	Edges	Rocks/Talus	**other**
	Dusky Flycatcher	*Empidonax oberholseri*	X			X													X		X	
	Hammond's Flycatcher	*Empidonax hammondii*	X			X						X										
	Pacific-slope Flycatcher	*Empidonax difficilis*		X	X	X	X	X	X			X		X								
Swallows	Purple Martin	*Progne subis*					X	X	X		X			X	X					X		
	Tree Swallow	*Tachycineta bicolor*	X			X			X	X	X	X		X	X							
	Violet-green Swallow	*Tachycineta thalassina*	X						X	X	X	X		X	X					X	X	cliffs
	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	X						X	X	X	X							X		X	burrows, cliffs
	Cliff Swallow	*Petrochelidon pyrrhonota*	X						X	X	X	X							X		X	cliffs
	Barn Swallow	*Hirundo rustica*	X						X		X								X		X	caves
	Bank Swallow	*Riparia riparia*	X						X	X	X								X			burrows, cliffs
Corvids	Gray Jay	*Perisoreus canadensis*	X	X	X	X	X	X														
	Steller's Jay	*Cyanocitta stelleri*		X	X	X	X	X														
	American Crow	*Corvus brachyrhynchos*	X	X	X	X	X	X		X										X		
	Common Raven	*Corvus corax*					X	X													X	cliffs, caves
	Clark's Nutcracker	*Nucrifraga columbiana*	X	X	X	X	X	X														
Tits/ Nuthatches/ Creepers	Black-capped Chickadee	*Poecile atricapillus*	X	X	X	X	X	X				X	X	X	X				X	X		
	Chestnut-backed Chickadee	*Poecile rufescens*		X	X	X	X	X				X		X	X							
	Mountain Chickadee	*Poecile gambeli*	X	X	X	X	X	X				X		X	X				X	X		
	Common Bushtit	*Psaltriparus minimus*	X	X	X							X							X	X		moss
	Red-breasted Nuthatch	*Sitta canadensis*		X	X	X	X	X				X		X	X							bark
	White-breasted Nuthatch	*Sitta carolinensis*	X									X	X	X	X							bark, moss, lichen
	Brown Creeper*	*Certhia americana*	X	X	X		X	X				X		X	X							moist, bark
Wrens	Bewick's Wren	*Thryomanes bewickii*	X							X			X	X					X	X		
	House Wren	*Troglodytes aedon*	X											X	X				X	X		bark
	Winter Wren	*Troglodytes troglodytes*		X	X		X	X					X		X				X			moss, bark
	Marsh Wren	*Cistothorus palustris*							X	X	X								X			
Dippers	American Dipper	*Cinclus mexicanus*							X		X		X								X	
Kinglets/ Thrushes	Golden-crowned Kinglet	*Regulus satrapa*		X	X		X	X				X										lichens
	Ruby-crowned Kinglet	*Regulus calendula*	X	X	X							X							X			
	Western Bluebird*	*Sialia mexicana*	X	X	X					X				X	X	X		X		X		open woodlands
	Mountain Bluebird	*Sialia currucoides*	X											X	X						X	>5000'
	Townsend's Solitaire	*Myadestes townsendi*	X	X	X	X	X	X					X									
	Swainson's Thrush	*Catharus ustulatus*		X	X		X	X				X							X			moist conditions
	American Robin	*Turdus migratorius*	X	X	X	X	X	X												X		
	Varied Thrush	*Ixoreus naevius*		X	X	X	X	X											X			litter
	Hermit Thrush	*Catharus guttatus*	X	X	X		X	X											X			
Waxwings	Cedar Waxwing	*Bombycilla cedrorum*	X	X	X					X		X							X			berries

			Habitat Association[1]									Habitat Elements[1]										
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Shrikes	Northern Shrike	*Lanius excubitor*	X							X				X					X	X		
	Loggerhead Shrike	*Lanius ludovicianus*	X																X	X		
Vireos	Cassins Vireo	*Vireo cassinii*		X	X			X				X										oak
	Hutton's Vireo	*Vireo huttoni*		X	X			X		X		X							X	X		
	Warbling Vireo	*Vireo gilvus*		X	X			X		X		X							X	X	X	
	Red-eyed Vireo	*Vireo olivaceus*		X	X			X	X			X										
Warblers	Orange-crowned Warbler	*Vermivora celata*	X																X	X		
	Yellow Warbler	*Dendroica petechia*	X							X									X			
	Yellow-rumped Warbler	*Dendroica coronata*	X	X	X			X				X							X			
	Black-throated Gray Warbler	*Dendroica nigrescens*	X	X	X							X							X	X		
	Townsend's Warbler	*Dendroica townsendi*		X	X		X	X				X										
	MacGillivray's Warbler	*Oporonis tolmiei*	X	X	X		X	X				X							X		X	
	Common Yellowthroat	*Geothlypis trichas*	X						X	X	X								X			
	Wilson's Warbler	*Wilsonia pusilla*	X	X	X					X		X							X		X	
Tanagers/ Grosbeaks/ Buntings	Western Tanager	*Piranga ludoviciana*		X	X	X	X	X				X								X		
	Black-headed Grosbeak	*Pheucticus melanocephalus*		X	X																	
	Snow Bunting	*Plectrophenax nivalis*	X																X			
Sparrows	Spotted Towhee	*Pipilo maculatus*	X	X	X								X						X	X		litter
	Savannah Sparrow	*Passerculus sandwichensis*	X							X									X			
	Fox Sparrow	*Passerella iliaca*	X									X							X	X		
	Song Sparrow	*Melospiza melodia*	X	X	X					X			X						X	X		
	Lincoln's Sparrow	*Melospiza lincolnii*	X							X									X			
	Golden-crowned Sparrow	*Zonotrichia atricapilla*	X										X						X			
	White-crowned Sparrow	*Zonotrichia leucophrys*	X										X						X	X		
	Dark-eyed Junco	*Junco hyemalis*	X	X	X		X	X					X						X	X		
	Lark Sparrow	*Chondestes grammacus*	X																X			
	Chipping Sparrow	*Spizella passerina*	X																X	X		
Troupials	Red-winged Blackbird	*Agelaius phoeniceus*							X	X	X								X			
	Brewer's Blackbird	*Euphagus cyanocephalus*	X							X									X			
	Brown-headed Cowbird	*Molothrus ater*	X	X	X														X	X		
	Northern Oriole	*Icterus galbula*		X	X					X												
	Western Meadowlark	*Sturnella neglecta*	X																X			
Finches	House Finch	*Carpodacus mexicanus*	X																X	X		
	Purple Finch	*Carpodacus purpureus*	X	X	X		X	X				X							X			flowers
	American Goldfinch	*Carduelis tristis*	X																X			
	Pine Siskin	*Carduelis pinus*		X	X	X	X	X				X							X			
	Red Crossbill	*Loxia curvirostra*					X	X				X							X			

Group	Common Name	Scientific Name	Habitat Association[1]: Forest Stage: Open	Hardwood	Mixed	Young	Mature	Old-growth	Aquatic: Rivers, Streams	Wetlands/Riparian	Lakes, Ponds	Habitat Elements[1]: Canopy Layers	Downed Wood	Snags	Tree Cavities	Hollow Trees	Large Branches	Mistletoe	Shrubs, Forbs, Grasses	Edges	Rocks/Talus	other
	Evening Grosbeak	*Coccothraustes vespertinus*			X	X	X	X				X										
Mammals (63 species)																						
Bats	Big Brown Bat*	*Eptesicus fuscus*	X		X		X	X	X	X	X			X	X	X				X	X	bark, caves
	Silver-haired Bat*	*Lasionycteris noctivagans*					X	X	X	X	X			X	X	X					X	bark, caves
	Hoary Bat*	*Lasiurus cinereus*	X	X	X		X	X	X	X	X	X		X					X	X		caves
	Townsend's Big-eared Bat*	*Plecotus townsendii*	X				X	X	X	X	X	X				X				X		caves
	California Myotis*	*Myotis californicus*		X			X	X			X			X	X	X					X	bark, caves
	Long-eared Myotis*	*Myotis evotis*		X	X		X	X			X			X					X		X	bark, caves
	Keen's Myotis*	*Myotis keenii*					X	X			X			X	X	X				X	X	caves
	Little Brown Myotis*	*Myotis lucifugus*					X	X			X			X	X	X				X	X	bark, caves
	Fringed Myotis*	*Myotis thysanodes*	X				X	X			X			X	X	X				X	X	bark, caves
	Long-legged Myotis*	*Myotis volans*	X	X	X		X	X			X			X	X	X				X	X	bark, caves
	Yuma Myotis*	*Myotis yumanensis*	X	X	X		X	X		X	X			X	X	X				X	X	bark, caves
Shrews	Marsh Shrew	*Sorex bendirii*							X	X												
	Masked Shrew*	*Sorex cinereus*		X	X	X	X	X		X			X						X			moist, litter, burrows
	Montane Shrew	*Sorex monticolus*	X	X	X	X	X	X		X			X						X			litter, fungi, burrows
	Northern Water Shrew*	*Sorex palustris*							X	X	X		X						X	X		
	Trowbridge's Shrew	*Sorex trowbridgii*		X	X	X	X	X					X									fungi, burrows, litter
	Vagrant Shrew	*Sorex vagrans*	X	X	X	X	X	X	X	X									X			litter
Moles	Shrew-mole	*Neurotrichus gibsii*	X	X	X	X	X	X	X				X									litter, burrows
	Coast Mole	*Scapanus orarius*	X				X	X					X						X			litter, burrows
	Townsend's Mole	*Scapanus townsendii*	X																X			burrows, roots
Rats/Mice	Bushy-tailed Woodrat	*Neotoma cinerea*	X				X	X					X	X	X	X		X	X		X	fungi, caves, cliffs
	Deer Mouse	*Peromyscus maniculatus*	X	X	X	X							X						X	X		fungi, bark, litter, burrows
	Keen's Deer Mouse	*Peromyscus keeni*					X	X					X									
	Southern Red-backed Vole	*Clethrionomys gapperi*		X			X	X					X						X			fungi, litter, lichens
	Long-tailed Vole	*Microtus longicaudus*	X							X		X							X			burrows
	Creeping Vole	*Microtus oregoni*	X										X						X			fungi, litter, burrows
	Townsend's Vole	*Microtus townsendii*	X							X									X			litter, tubers, burrows
	Water Vole	*Microtus richardsoni*	X						X				X						X			burrows
	Heather Vole	*Phenacomys intermedius*	X	X	X	X				X		X							X			burrows
	Pacific Jumping Mouse	*Zapus trinotatus*	X			X				X		X	X						X	X		fungi, burrows
	Muskrat	*Ondatra zibethicus*							X	X	X								X			burrows
Squirrels	Cascade Golden-mantled Ground Squirrel	*Spermophilus saturatus*	X	X	X	X	X	X					X								X	burrows, open forest
	Townsend's Chipmunk	*Tamias townsendii*	X										X						X	X	X	fungi, lichens
	Douglas' Squirrel	*Tamiasciurus douglasii*					X	X				X	X				X		X	X		fungi
	Northern Flying Squirrel	*Glaucomys sabrinus*					X	X					X	X	X	X	X	X				fungi, litter, moss

			Habitat Association[1]									Habitat Elements[1]										
			Forest Stage						Aquatic													
Group	Common Name	Scientific Name	Open	Hardwood	Mixed	Young	Mature	Old-growth	Rivers, Streams	Wetlands/Riparian	Lakes, Ponds	Canopy Layers	Downed Wood	Snags	Tree Cavities	Hollow Trees	Large Branches	Mistletoe	Shrubs, Forbs, Grasses	Edges	Rocks/Talus	other
	Hoary Marmot	*Marmota caligata*	X																X		X	burrows
	Yellow-bellied Marmot	*Marmota flaviventris*	X										X						X		X	burrows
Mtn Beavers	Mountain Beaver	*Aplodontia rufa*		X	X	X	X	X					X						X			burrows, deep moist soil
Beavers	Beaver	*Castor canadensis*	X	X	X				X	X	X								X			banks
Porcupines	Porcupine	*Erethizon dorsatum*	X			X	X	X					X			X			X	X	X	
Rabbits	Snowshoe Hare	*Lepus americanus*	X			X				X									X	X		burrows
Pika	Pika	*Ochotona princeps*	X																X		X	
Bear	Black Bear	*Ursus americanus*	X	X	X		X	X					X	X		X			X	X	X	tubers, bark, caves
	Grizzly Bear*	*Ursus arctos*	X	X	X		X	X		X			X						X	X	X	bark, caves
Procyonids	Raccoon	*Procyon lotor*	X	X	X	X	X	X	X	X			X	X	X	X			X		X	burrows
Mustelids	Marten*	*Martes americana*					X	X	X	X		X	X	X	X		X	X	X		X	burrows, stumps
	Fisher*	*Martes pennanti*					X	X		X			X	X	X	X	X	X	X			cliffs, stumps
	Short-tailed Weasel (Ermine)	*Mustela erminea*		X	X	X	X	X		X			X								X	burrows
	Long-tailed Weasel	*Mustela frenata*	X	X	X	X	X	X		X			X	X	X						X	burrows
	Mink	*Mustela vison*							X	X	X		X								X	burrows
	River Otter	*Lontra canadensis*							X	X	X		X						X		X	burrows
	Wolverine*	*Gulo gulo*					X	X		X			X			X					X	caves, snow
	Striped Skunk	*Mephitis mephitis*	X	X	X	X	X	X		X			X	X							X	bark, litter, burrows
	Spotted Skunk	*Spilogale gracilis*		X	X	X	X	X					X	X	X	X					X	tubers, litter, burrows, cliffs
Cats	Cougar	*Felis concolor*	X	X	X	X	X	X					X				X				X	cliffs
	Bobcat	*Lynx rufus*	X	X	X	X	X	X					X						X		X	cliffs, caves
	Canada Lynx*	*Lynx canadensis*	X	X	X	X	X	X					X						X		X	snoshoe hares, snow
Canids	Red Fox	*Vulpes vulpes*	X							X			X						X	X		burrows, berry-producing shrubs
	Coyote	*Canis latrans*	X	X	X	X	X	X		X									X			burrows, berry-producing shrubs
	Gray Wolf*	*Canis lupus*	X	X	X	X	X	X	X	X			X							X	X	caves, snow
Deer/Bovids	Elk	*Cervus elaphus*	X	X	X		X	X		X			X						X	X		
	Black-tail Deer	*Odocoileus hemionus*	X	X	X		X	X		X			X						X	X		
	Mountain Goat	*Oreamnos americanus*	X																	X	X	moss, lichen, cliffs, snow

[1]Source: Cedar River Watershed Habitat Conservation Plan (CRW-HCP), Johnson and O'Neil (2001), Christy and West (1993), CRMW staff professional judgement.

Appendix C. Site Selection and prioritization criteria for ecological thinning, restoration thinning, and upland planting projects in the CRMW.

The following sections detail the site selection and prioritization criteria for ecological thinning (Section 1.0), restoration thinning (Section 2.0), and upland planting projects (Section 3.0), as identified through informed professional opinion by the UFRIDT. Criteria are listed in general order of importance and generally divided into coarse- and fine-filter site selection criteria, and stand- and landscape-level prioritization criteria. Primary and secondary levels of site selection criteria are specified, where appropriate, to aid in the prioritization of project sites. Many of the prioritization criteria are difficult to quantify and are included to provide a qualitative framework for upland forest restoration planning. Not all prioritization criteria will be applied to all projects.

1.0 Ecological Thinning Projects

Forested areas "that will receive the highest priority for ecological thinning will be those that are the most overstocked based on size, age, and species and have the least biological and structural diversity and have the greatest potential for beneficial results" (CRW-HCP 4.2-37). These areas are likely in the competitive exclusion stage of forest development. While forest conditions are ecologically linked, this section addresses each criterion separately.

1.1 Coarse-Filter Site Selection Criteria

Tree Density – The competitive exclusion stage of forest succession exhibits competition among dominant and co-dominant trees, which results in reduced diameter growth rates, and increased stress resulting in competition mortality. Lowering the density of trees in the mid and upper canopy, in areas with greater than 300 trees per acre (TPA), while maintaining appropriate stocking levels, will maintain or increase growth rates of the remaining trees, decreasing the time to achieve the large tree component of late-successional forests, and ultimately increase large snag and downed wood recruitment. Increased light exposure to the understory from thinning is also expected to increase understory plant diversity. While areas with greater than 400 TPA of the targeted age class would benefit most from ecological thinning, areas with greater than 1,000 TPA would be more likely to be an appropriate diameter for restoration thinning.

Tree Diameter – Tree age and tree density directly influence tree diameter. Forest areas with targeted tree ages (30-60+ years) and densities (greater than 400 TPA) typically exhibit mean quadratic diameters greater than 8 inches diameter at breast height (Qdbh). Areas with smaller diameters (less than 8 inches) are likely candidates for restoration thinning (see Section 5.3.1). Areas with large-diameter trees (e.g., greater than 20 inches Qdbh) may be naturally undergoing canopy differentiation in the upper canopy layer, in which case ecological thinning would be of less benefit.

Stand Density Index and Relative Density – Stand density index (SDI) is a relative measure of stand density that converts a stand's current density into a density at a reference diameter size. Relative density (RD) is based on SDI and is a metric that generally indicates tree competition and growth rate. Competition mortality dominates stand dynamics in areas that have a RD greater than 65, while a stand is considered no longer completely forested with a RD below 20. Vigorously growing stands are typically between 35 and 50.

SDI can be defined as:

$$SDI = TPA\ (Qdbh/10)^{1.605} \qquad (1)$$

where TPA is trees per acre (tree density) and Qdbh is the quadratic mean diameter (Reineke 1933). The Qdbh is the diameter corresponding to the average basal area per tree at breast height. The maximum SDI for 10-inch dbh Douglas fir, for example, is 587 trees per acre (Long 1985).

RD can be defined as:

$$RD = (SDI/SDI_{max}) \times 100 \qquad (2)\text{, or similarly:}$$

$$RD = BA/(Qdbh^{0.5}) \qquad (3)$$

where BA is the basal area per acre (Curtis 1982). Douglas-fir dominated stands with an RD of more than 50 (SDI greater than 290) may have characteristics that would benefit from ecological thinning (e.g., lowering the RD would maintain or increase tree growth rate).

Tree Age – Second-growth forested areas between 30 and 60 years of age, and potentially up to 100 years, typically exhibit characteristics that would most benefit from ecological thinning. These forests are often in the competitive exclusion or biomass accumulation successional stage, depending on tree density. The first 50 years of tree growth largely determines the form of individual trees (Hunter 2001). Ecological thinning in relatively young stands, therefore, is expected to produce more dramatic results than thinning in older stands where tree diameters and crown structures are already established.

Canopy Closure – Higher density forest areas typically result in canopy closures of greater than 70 percent, which often indicates relatively high competition mortality rates, slowed growth, and low understory plant diversity (Franklin et al 2002, Carey et al 1999b). Ecological thinning projects will reduce canopy closure and will be primarily considered for forested areas with greater than 90 percent canopy closure.

Site Class – Though relatively higher site class areas (e.g., high tree growth potential generally based on soil conditions) would likely exhibit a positive response to ecological thinning faster than lower site class areas, higher site class areas will also typically emerge from the competitive exclusion stage without restoration activities faster than lower site class areas (Oliver and Larson 1996). The poorest growing areas (e.g., site class V) may not rapidly, if ever, respond to ecological thinning. Over 80 percent of the CRMW is in site classes III, IV, and V. Ecological thinning will likely most benefit site class IV, but will also be considered in other site classes.

Slope – Though forested areas on all types of slopes in the CRMW would likely benefit from ecological thinning, the technical aspects of thinning trees and removing some of the logs will likely limit accessibility. The risks of soil erosion and compaction and of damage to remaining trees (e.g., bark injuries) will likely limit the benefits of ecological thinning to slopes less than 35 percent. Some areas with 35 to 75 percent slopes may be considered where conditions (e.g., stable soils) and methods (e.g., helicopter thinning) are appropriate to minimize risks.

Aspect – Though the aspect (or exposure) of a forested area will not generally play a major role in determining an appropriate site for an ecological thinning project, aspect is a determinant in the growing potential and species composition of a site. South and west facing slopes are exposed to greater light energy, which can sometimes lead to less moisture and limit tree establishment and growth. Decreasing the influence of competition may benefit these areas by maintaining or increasing tree growth.

Elevation – Elevation is the major determinant of the forest types or zones found in the CRMW (Franklin and Dyrness 1988). The western hemlock zone is found generally under 3,000 feet asl, the Pacific silver fir zone between 3,000 and 4,500 feet asl, and the mountain hemlock zone above 4,500 feet asl. Ecological thinning will benefit areas in the western hemlock and Pacific silver fir zones and generally will be considered for areas under 4,500 feet asl. Forested areas in the mountain hemlock zone have typically not been utilized for timber production in the past and may not benefit from thinning.

1.2 Fine-Filter Site Selection Criteria

Tree Diameter Growth – The competition between trees in the competitive exclusion stage of forest succession limits diameter growth, as expressed by the width of annual growth rings at breast height, also known as the mean annual increment (MAI). Though dependent on tree species in the stand, forested areas exhibiting greater than 15 rings per inch will likely exhibit an increase in growth rate following ecological thinning, while those that have 7 to 15 rings per inch will likely maintain or increase their growth rate.

Live Crown Ratio – The competition for light in high-density forest areas can result in relatively low live crown ratios, or the depth of the live part of the crown as a percentage of the total height of a tree. But trees with higher live crown ratios will likely benefit greater from ecological thinning due to the greater ability to capture increased light energy. Ecological thinning will result in a rapid positive growth response from trees when the live crown ratio is greater then 40 percent and will have a much slower affect when the ratio is less than 30 percent.

Canopy Layering – Forest areas in the competitive exclusion stage typically exhibit one tree canopy layer (the upper canopy), while late-successional forest have more than one layer (main canopy, middle canopy, and understory trees and shrubs). Ecological thinning would most benefit one canopy layer forests by helping to establish understory layers, while multi-canopy layer areas are likely already emerging from the competitive exclusion stage.

Tree Species Diversity – Though tree species diversity in the overstory canopy of forests in the Pacific Northwest is typically relatively low, several species are ecologically suited to most forested areas. Ecological thinning will most benefit areas where one species makes up over 80 percent of the overstory tree abundance, by increasing the relative abundance of the less dominant species. Thinnings will also be considered for areas where the dominant species makes up 45 to 80 percent of overstory tree abundance (e.g., there are three species present with at least 10 percent abundance).

Understory Development – The high canopy closure of forested areas in the competitive exclusion stage typically results in a depauperate understory. Areas with a developed understory, in terms of occurrence and species diversity, likely do not have a closed overstory canopy. Ecological thinning would increase the light energy reaching the forest floor, which would increase the occurrence and diversity of understory plant species. Forested areas with less than 40 percent ground covered by understory would likely benefit from ecological thinning, while areas with less than 10 percent would be primarily targeted for thinning projects.

Understory Species Diversity – The species diversity of vascular plant species (e.g., small trees, shrubs, herbs, and grasses) is typically greater in the understory than in the overstory, though it can still be dominated by a few species in the understory. Ecological thinning will most benefit areas where one understory species represents over 65 percent of the understory ground cover, by providing more growing opportunities to other species. Areas will also be considered for thinning where one species represents 35 to 65 percent of understory ground cover.

Snags – Large standing dead trees (snags) provide a valued habitat component in late-successional forests which is generally lacking from younger forests originating after clearcut harvesting. In these second-growth areas, increasing or maintaining the growth of trees will facilitate the recruitment of large snags in the future. Areas with less than two snags that are greater than 15 inches dbh and over 20 feet tall per acre will most benefit from ecological thinning.

Downed Wood – Large downed wood is also a valued habitat component in late-successional forests that can be lacking from younger forests. Similar to snags, increasing or maintaining tree growth through ecological thinning will shorten the time to the natural recruitment of large downed wood in the future. Areas with less than 500 cubic feet per acre of downed wood with a minimum diameter of 6 inches (e.g., 18 50-foot pieces with an average diameter of 10 inches) will most benefit from ecological thinning.

Horizontal Structural Diversity – Late-successional forests typically exhibit a shifting mosaic of gaps (e.g., canopy openings from individual tree fall) which leads to a relatively high degree of horizontal structural diversity across the landscape. This is characterized by a relatively wide variance in tree densities, mid-canopy branching, and understory distributions. Areas that exhibit homogeneous horizontal structural diversity will benefit most from ecological thinning.

1.3 Stand-Level Prioritization Criteria

Water Quality Impacts – Ecological thinning of forested areas which results in no or limited risk of water quality impacts will be considered before areas that pose a greater risk. Areas that pose a significant risk will not be thinned. It is anticipated that thinning will benefit water quality over the long-term, by facilitating the restoration of a water cycle more typical to Pacific Northwest old-growth forests.

Stand Size – Forest areas generally will not be considered for ecological thinning unless they are greater than 100 acres in size. This size is large enough to affect forest habitat on a scale appropriate for wildlife with relatively large home ranges (e.g., northern spotted owl, pileated woodpecker, fisher, marten). Ecological thinning projects will often employ various treatments and monitoring controls, where the effects of thinning are measurable. The thinning of smaller areas will generally not provide a suitably large area for such monitoring analysis. Thinning of smaller areas in proximity to one another and to late-successional habitat, however, may provide significant ecological benefits and could be considered as a single project.

Plant Species Diversity – Ecologically thinning forested areas that have relatively low plant diversity (e.g., overstory tree abundance is dominated by a single species) would be more ecologically beneficial than thinning areas that already exhibit relatively high levels of diversity. Thinning would likely increase the variability of growing conditions under which more plant species could exist. Areas where a single tree species makes up over 80 percent abundance of the dominant tree layer, for instance, will greatly benefit from thinning the dominant species, thereby increasing the relative density of other tree species present and opening the canopy to allow for variable understory conditions.

Structural Complexity– Areas that exhibit relatively low structural complexity, both horizontally and vertically, will likely benefit more from ecological thinning than areas with relatively high structural heterogeneity. Thinning will result in increasing tree density variability and accelerating the time to grow large trees. This will increase structural diversity by increasing canopy layering, providing for understory plant diversity, and providing a recruitment base for large snags and downed wood. Forested areas that are relatively homogeneous in structure will be targeted for ecological thinning projects.

Specific Wildlife Benefit – Forested areas where ecological thinning could specifically benefit CRW-HCP listed species will be thinned before areas without known specific benefits. Ultimately, ecological thinning is meant to benefit late-successional forest dependent species by lowering the time to the advent of many late-successional characteristics. Within this context, specific wildlife concerns could exist that would prioritize thinning (e.g., proximity to relatively high density of nest sites, proximity to riparian areas or wetlands).

Riparian Habitat – Though the thinning of riparian forests is dealt with more specifically by the Riparian Restoration Strategic Plan, it is unlikely that any ecological thinning project in the CRMW will be free of riparian issues. A riparian ecologist on the WMD staff will be consulted regarding riparian concerns with all potential restoration projects. Areas that are dominated by riparian issues will be suggested to the Riparian Restoration ID Team as candidates for their thinning projects. Ecological thinning projects will therefore occur in areas where the riparian issues are not the dominant concerns of the thinning project.

Road Access – One of the products of a history of commercial timber harvest in the CRMW is an extensive road network. Though this network provides access to most forest areas that are candidates for ecological thinning, it also provides a significant source of sediment to streams. Restoration of a more natural water cycle through the decommissioning of non-essential roads is one of the major management goals of the CRW-HCP. The scheduling and location of the decommissioning projects, however, may prioritize thinning projects that are accessible by these non-essential roads to occur before their decommissioning. Also, thinning projects that require the construction or reconstruction of roads will have lower priority than areas that can be treated using the existing infrastructure.

Seasonal Limitations – Though ecological thinning projects can be conducted at lower elevations in the CRMW all year around, access to upper elevations is limited by snow for many months of the year. The limited availability of upper elevation forests may give ecological thinning projects at higher elevations a priority in the snow free portions of the year over lower elevation forests.

Thinning Method – The appropriate methods and equipment required to conduct ecological thinning projects vary with existing road access, slope, soil type, tree size, and whether thinned trees will be removed from the site. A method will be chosen for each project that will minimize damage to the residual trees, soil, snags, and downed wood. The economics of each method varies with time, as does technology itself. Areas that would benefit from ecological thinning may be prioritized based on the types of thinning methods available at a given time. For example, ground-based operations (e.g., processor and forwarder) can currently operate efficiently on slopes less than 35 percent and can result in minimal residual damage. Cable thinning, on the other hand, can operate on steeper slopes but often is accompanied by greater damage. Helicopter thinning will also be investigated as an option.

Likelihood of Re-entry – The prescriptions for each ecological thinning project will be based on achieving the greatest perceived ecological benefits for the site. Areas where this can be accomplished by one entry may be preferred over areas where more than one entry is envisaged to cause further disturbance. In other words, areas where an appropriate thinning prescription results in a tree density that will not require further thinning in the future may be preferred over multiple thinning disturbances.

Monitoring Efficiency – Due to cost constraints, not all ecological thinning projects will be monitored for their effectiveness in reaching the management goals (see Section 8). Some projects will be selected for monitoring, however, and in these projects efficiency is a factor in prioritizing selection of thinning projects. In potential thinning areas that would have monitoring as an objective, areas that provide the criteria needed for long-term effectiveness monitoring (e.g., large enough to incorporate suitably sized treatment and control sites, long-term road access) will be prioritized ahead of areas that do not.

Cultural Resources – Areas where ecological thinning does not pose a significant risk to the cultural resources of the CRMW will be prioritized ahead of areas where risks are significant. Additionally, the financial costs of assessing risk (e.g., cultural resource surveys) are a concern in planning for thinning. Areas that would require expensive surveys (e.g., low slopes near open water) to enable ecological thinning may not be as high priority as areas where surveys are not required.

Affordability – Though ecological thinning projects are intended to be conducted on an ecologically beneficial basis, the economic costs of conducting a management action also need to be considered when working with limited budgets. The logistics and costs of planning and implementing a project (e.g., project planning, forest inventory, cultural resources inventory, project layout, thinning costs, contract compliance, monitoring, snag creation) will be weighed against the predicted ecological benefits of completing the project. While ecological thinning project costs cannot exceed annual budgets, we will be working under the goal of achieving the greatest ecological benefit for the least financial cost. Areas which can be treated more economically, or where larger areas can be treated for similar costs, may have priority.

1.4 Landscape-Level Prioritization Criteria

Proximity to Late-Successional Habitat (Connectivity) – Wildlife populations dependent on late-successional forest habitat are limited by the juxtaposition or connectivity of this habitat across the landscape (Pulliam 1988, USDA and USDI 1994, Wiens 1997). Habitat connectivity is generally a function of the amount and distribution of suitable habitat on the landscape, the density of wildlife populations in that landscape (e.g., size of home range), and the ability of individuals to disperse between patches of suitable habitat. Priority will be given to potential ecological thinning sites that improve the habitat connectivity for late-successional dependent species (e.g., northern spotted owl, northern goshawk, pileated woodpecker, fisher, marten), or are in close proximity to late-successional forest habitat. The definition of proximity varies with the dispersal capabilities of a species, but is generally defined here by the results of a connectivity analysis using the PATCH model (see Section 6.4.4)

Quality of Late-Successional Habitat – All late-successional forest does not provide the same habitat value. Some forest areas may provide good habitat that supports a relatively stable population of late-successional dependent wildlife species and is a source of migrating individuals, while other areas provide habitat that will not support a population without constant migration from outside (e.g., sink). Priority will be given to potential ecological thinning sites that are in relative close proximity to late-successional forest that provides source habitat for dependent wildlife species, ahead of areas in proximity to late-successional forest that provides sink habitat. These habitats can be identified in a PATCH model analysis (see Section 6.4.4).

Proximity to CRMW Boundary – Though the CRMW will generally be managed as a forest reserve over the course of the CRW-HCP, forested lands outside and adjacent to the CRMW, particularly those adjacent to the western portions of the CRMW, will be subject to continued rotation harvest or conversion to other landcover types. Potential ecological thinning sites near the CRMW boundary are therefore subject to edge effects associated with both landowner boundaries (trespass, wildfire, exotic species) and ecotones (windthrow). To minimize these effects in ecological thinning projects, priority could be given to potential sites away from the CRMW boundary. To maximize habitat connectivity with patches of late-successional habitat outside the CRMW, however, particularly to land owned by the USDA Forest Service (USFS) that is adjacent to eastern portions of the CRMW, priority could be given to potential sites near the boundary.

Sub-Basin Planning – Landscape and water quality concerns could be addressed by prioritizing ecological thinning projects based on their location within watershed sub-basins in the CRMW (e.g., concentrate restoration projects within a basin until a natural functioning basin is restored). Sub-basin prioritization could either be based on the most need (e.g., basins with the most anthropogenic disturbance) or the least effort (e.g., basins with the most intact natural processes), or other criteria.

Restoration Patch Size and Juxtaposition – Restoration patch size is defined here as the size of a potential restoration planning area that will support most late-successional forest dependent species. The patch can be subdivided into several restoration projects. The juxtaposition of restoration patches will allow for improved habitat connectivity between existing old-growth forest and other portions of the CRMW. A restoration patch size of greater than 1,000 acres will incorporate home ranges of all but the widest ranging late-successional forest dependent species.

Upper/Lower CRMW Connectivity – Historic management has produced significantly different forest habitat conditions in the upper (higher elevations to the east) and lower (lower elevations to the west) CRMW. The upper watershed contains much of the remaining old-growth forest in the CRMW, in discrete patches surrounded by a matrix of second-growth forest that generally ranges in age from 10 to 50 years. This is typical of higher elevation forests in the region, where USFS management has conserved the amount of late-successional forest that remain. In contrast, the forests of the lower CRMW were generally clearcut between 1900 and 1940 and are currently dominated by 60 to 80 year-old second growth forest areas. The forests of the lower CRMW are unique to the region, however, where forestlands are subject to rotational harvests and landcover conversion to non-forest habitat types. Though very little late-successional forest habitat currently exists in the lower CRMW, it will eventually dominate the area under CRW-HCP reserve status management. For wildlife species dependent on late-successional forests to eventually exist in the lower CRMW, they must disperse from existing late-successional forest areas, likely in the upper CRMW. Priority will be given to potential ecological thinning sites that improve late-successional forest habitat connectivity between the upper and lower portions of the CRMW.

Proximity to Other Ecological Thinning Sites – Treating potential ecological thinning sites that are in relatively close proximity to one another will increase the spatial benefits of ecological thinning by decreasing the time to the advent of late-successional forest habitat characteristics over a larger spatial scale. This could allow for more variability in habitat metrics and allow for larger, more stable populations of late-successional-dependent species. Priority will be given to potential ecological thinning sites that are in close proximity to one another.

Temporal Considerations – The CRW-HCP places a 50-year planning horizon on CRMW forest management, which extends until 2051. Management priorities after that time are unknown. The reserve status of the forests will allow them to continue to grow through successional stages over this 50 years, regardless of restoration efforts. The benefits of restoration projects could be measured by the difference in late-successional habitat in 2051 with and without restoration intervention. Because the time scale needed to recreate characteristics of late-successional forests is longer than 50 years, detecting differences may be problematic. Priority could be given to those potential ecological thinning sites that would most benefit late-successional forest habitat, in terms of amount and distribution, by the end of the CRW-HCP implementation period.

Coordination with Other Restoration Projects – Concentrating and coordinating restoration efforts in a common area may decrease the costs of implementing the projects. Planning, data collection, and long-term monitoring could be streamlined to accommodate multiple projects in the same area at the same time. Prioritization could be given to potential ecological thinning sites where they are in close proximity to other restoration efforts (e.g., restoration thinning, upland planting, riparian restoration, aquatic restoration, and/or road restoration).

2.0 Restoration Thinning Projects

Forested areas "that will receive highest priority for restoration thinning will be those that: (1) are most over-stocked, based on age, species, and site characteristics; (2) exhibit signs of severe competition and stress and determined to be at greatest risk of causing catastrophic damage; and (3) have the greatest potential for beneficial results" (CRW-HCP 4.2-36). These areas are likely early in the competitive exclusion stage of forest development. Again, while forest conditions are ecologically contingent upon one another, this section addresses each characteristic separately. Restoration thinning site selection and prioritization criteria are summarized in Table 7.

2.1 Coarse-Filter Site Selection Criteria

Tree Density – Relatively high densities of trees are typical in early stages of the competitive exclusion stage as small trees vie for resources. Restoration thinning will decrease the competition between trees, which will increase or maintain growth rates. Forested areas with more than 1,000 TPA will most benefit from restoration thinning, while areas with 500 to 1,000 TPA will also be considered for thinning.

Tree Diameter – Relatively young and dense forest areas typically have small diameter trees. Restoration thinning will be most appropriate in areas that have trees with less than 8 inches dbh. There should, however, be no more than 300 TPA greater than 7 inches dbh. These areas may be more appropriate for ecological thinning, since restoration thinning in these areas will result in large amounts of slash, which serves as wildfire fuel.

Tree Age – Trees in different forest zones reach the early stages of the competitive exclusion stage at different ages based on their differing growth rates that are largely dependent on autecology, climate, and site class conditions. Forested areas in the western hemlock zone in the CRMW (e.g., less than 3,000 feet asl) will likely reach a size that would benefit from restoration thinning at 15 to 20 year old, or maybe not until 30 years of age. Areas in the Pacific silver fir zone (3,000 to 4,500 feet asl), however, will not likely reach an appropriate size until 20 to 30 years of age, or maybe as long as 40 years.

Canopy Closure – In addition to comparatively high tree densities, forested areas in the competitive exclusion stage of forest development typically have dense canopies, which results in competition for light energy, slower tree growth, and competition mortality. Restoration thinning will most benefit areas with greater than 80 percent canopy closure, by providing more growing space per tree. Areas with 60 to 80 percent canopy closure will also be considered for restoration thinning.

Slope – Though there are no slope limitations to restoration thinning based on the methods of thinning trees (e.g., no heavy equipment), it is likely that forested areas less than 35 percent slope will have less access problems. All slopes, however, could benefit from restoration thinning.

Aspect – Similar to ecological thinning, all aspects will likely benefit from restoration thinning. Young tree growth on southwestern slopes, however, may be limited by dry conditions resulting from greater light energy exposure. Decreasing the influence of competitive competition may help these areas maintain or increase tree growth.

Elevation – Forested areas in the western hemlock and Pacific silver fir zones (e.g., less than 4,500 feet asl) will most benefit from restoration thinning.

2.2 Fine-Filter Site Selection Criteria

Tree Species Diversity –As with ecological thinning, restoration thinning will most benefit forested areas where one tree species makes up over 80 percent of tree abundance, by increasing the relative abundance of less dominant species. Thinning will also be considered for areas where the dominant species makes up 45 to 80 percent of the tree abundance (e.g., there are three species present with at least 10 percent abundance).

2.3 Stand-Level Prioritization Criteria

It is possible that all forested areas in the CRMW that would most benefit from restoration thinning can be thinned in the first 10 to 15 years of the CRW-HCP (by 2016). Prioritization for restoration thinning projects is therefore less crucial to planning than for ecological thinning projects, where the extent of forest that would benefit from thinning exceeds the financial ability to thin. The timing in which areas are restoration thinned may be important, however, due to logistical constraints (e.g. road decommissioning) and ecological concerns (e.g. continuity of fuels and fire hazard). The criteria for prioritizing restoration thinning projects are similar to those for ecological thinning projects.

Water Quality Impacts – Potential restoration thinning sites will not be thinned if they pose a significant risk to water quality.

Stand Size – Potential restoration thinning sites generally will have priority for consideration for thinning if they are greater than 10 acres in size. Sites that are smaller could be thinned if they are in close enough proximity to other potential thinning sites to be considered as a single project.

Road Access – Priority will be given to potential restoration thinning sites where road accessibility may be compromised seasonally (e.g., snow) or permanently in the future (e.g., road decommissioning).

Tree Diameter – Priority will be given to potential restoration thinning sites that are nearing the 8-inch dbh break between restoration and ecological thinning. These sites will likely be a low priority for ecological thinning in the near future, but would ecologically benefit from thinning now.

Plant Species Diversity – Priority will be given to potential restoration thinning sites where a single tree species makes up over 80 percent of the abundance of all trees.

Affordability – Priority will be given to the potential restoration thinning sites that provide the greatest ecological benefit for the restoration cost.

Riparian Habitat – Potential sites where there are not significant riparian concerns will have a higher priority for restoration thinning.

Thinning Method – Potential restoration thinning sites that provide enough space for varying treatments (e.g., different thinning density) will have a higher priority for thinning than smaller areas where one treatment would appropriate.

Likelihood of Re-entry – It is likely that some restoration thinning sites would benefit from ecological thinning at some time in the future. Potential restoration thinning sites where the probable need for future ecological thinning is lowest will have priority over those sites where re-entry is more likely.

Monitoring Efficiency – Priority will be given to potential restoration thinning sites that provide the criteria needed for long-term effectiveness monitoring (e.g., spatially large enough for treatments and controls, long-term road access).

2.4 Landscape-Level Prioritization Criteria

Proximity to Late-Successional Habitat (Connectivity) – Priority will be given to potential restoration thinning sites that are in relative close proximity to late-successional forests and that improve connectivity between late-successional forest habitat.

Quality of that Late-Successional Habitat – Priority will be given to potential restoration thinning sites that are in relative close proximity to late-successional forest that provides good habitat to late-successional dependent wildlife species.

Proximity to CRMW Boundary – Priority could be given to potential restoration thinning sites that are adjacent to the CRMW boundary to maximize potential late-successional forest habitat connectivity with habitat outside the CRMW. Conversely, priority could be given to potential restoration thinning sites away from the boundary to minimize the edge effects associated with landowner boundaries (e.g., trespass, wildfire, exotic species) and forest ecotones (windthrow).

Sub-Basin Planning – Priority will be given to potential restoration thinning sites that are located within watershed sub-basins where restoration is a priority. Sub-basins could be prioritized based on either the most need (e.g., basins with the greatest anthropogenic influence) or the least effort (e.g., basins with the most intact natural processes).

Upper/Lower CRMW Connectivity – Priority will be given to potential restoration thinning sites that improve late-successional forest habitat connectivity between the upper and lower portions of the CRMW.

Proximity to other Restoration Thinning Sites – Priority will be given to potential restoration thinning sites that are in close proximity to one another, pending the hazards of wildfire.

Temporal Considerations – Priority will be given to potential restoration thinning sites that will most benefit late-successional forest habitat by the end of the CRW-HCP planning horizon (2051).

Coordination with other Restoration Projects - Priority will be given to potential restoration thinning sites that are in close proximity to other restoration efforts (e.g., ecological thinning, riparian restoration, road decommissioning).

3.0 Upland Restoration Planting Projects

Forested areas “that will receive highest priority for restoration planting will be those that have plant diversity much lower than expected, based on site characteristics, and those with the greatest potential for beneficial results” (CRW-HCP 4.2-35).

3.1 Site Selection Criteria

Site selection criteria of upland planting projects were not addressed using the coarse- and fine-filters approach, but rather with three objectives of biological diversification. They are addressed separately below:

Improving Tree Stocking Levels - Upland planting of trees will most benefit relatively young forest areas in the competitive initiation stage of forest succession (less than 15 years old) where natural tree regeneration or previous tree planting has not resulted in a tree density of at least 190 trees per acre. These areas are likely to be below 4,500 feet asl and of low growing potential (site class III to V and/or on southwestern-faced slopes). The potential planting sites should also have sufficient plantable spots per acre (e.g., places suitable to plant tree seedlings) to accommodate 190 trees per acre. Areas that continue to be under-stocked after several planting attempts may not warrant additional planting effort, although alternative restoration efforts may be explored. A summary of these criteria is included in Table 8.

Improving Tree Species Diversity at Other Restoration Sites - A goal for upland forest restoration projects in the CRMW, including ecological and restoration thinning, is to enhance biological diversity. Upland planting projects will be implemented in conjunction with ecological and restoration thinning projects where the current diversity has not reached its potential. Examples of this include planting shade tolerant species under a canopy of shade-intolerant species, planting root rot resistant species in areas infected by root rot, planting shade-tolerant conifers under a deciduous canopy, planting deciduous trees and shrubs under a conifer canopy, and planting on decommissioned roads. The suitability of these planting projects will be evaluated during the planning of those other restoration projects.

Improving Diversity of Other Plant Species - The planting of other species (shrubs, herbs, grasses, mosses, and lichens) will also improve the diversity in many upland areas. Planting of non-tree species will be used to enhance ecosystem processes such as the development of specific wildlife habitat structures, soil and soil flora development, epiphytic community succession, and forest structural development. A large focus of planting will include appropriate shrubs and deciduous trees that are rare on a project site but are important to ecological processes. Seedbank dependent forbs may also be planted that, due to past management disturbance, are not regenerating. In addition, some mosses, liverworts, and lichens provide habitat and food sources for arthropods and birds, aid in nutrient cycling, and contribute to organic matter of soil and litter. Planting of vascular species may be augmented by innovative techniques for seeding of lichens and bryophytes. Typically these species have short dispersal distances and past management in the CRMW has further increased the distances between seed sources. Seeding in forests of the appropriate age which lack nearby seed source may help contribute to the development of desired forest characteristics.

Additional upland forest restoration planting will explore opportunities to inoculate with parasites and pathogens. Although forest habitat management has historically attempted to eliminate forest parasites and pathogens, current research suggests that organisms such as dwarf mistletoe (*Arceuthobium spp.*) and tree rots (e.g., *Phellinus weirii*) drive key ecosystem processes in forested ecosystems (Castello et al. 1995). Dwarf mistletoe provides a food source for some wildlife species, creates witches' brooms that serve as nesting and cover habitat, and assists snag creation by weakening trees. Historically, the CRMW likely had patches of trees infected with mistletoe and other patches of mistletoe-free trees. Past management (specifically, clearcut timber harvesting) has probably altered the extent, distribution, and size of the populations of dwarf mistletoe in the CRMW. The extent of dwarf mistletoe in the CRMW needs to be determined. Another unusual species that may be considered for inoculation is heart rot, a pathogen important to the development of hollow trees and trees suitable for cavity excavation (Bull et al 1997). Damaging tops or boles of trees to allow heart rot to establish may be adequate, however it is possible that populations of heart rot fungi have also been lowered by past management and inoculation of selected trees may be required.

3.2 Stand-Level Prioritization Criteria

The criteria for prioritizing upland planting projects are similar to those for ecological and restoration thinning projects.

Water Quality Impacts – Upland planting will aid in stabilizing soil in areas where soil erosion is known to increase sedimentation in streams. Priority will be given to potential upland planting sites where planting will benefit water quality.

Stand Size – Potential upland tree planting sites generally will have priority for consideration for planting if they are greater than 10 acres in size. Sites that are smaller could be planted if they are in close enough proximity to other potential planting sites to be considered a single project, or as part of a larger ecological or restoration thinning project. The planting of other plant species may occur on any spatial scale, depending on what is ecologically appropriate.

Plant Species Diversity – Priority will be given to potential upland sites where planting will enhance the diversity of native plant species and therefore contribute to wildlife habitat, soil development, and ecosystem complexity. Planting may include trees, shrubs, forbs, grasses, mosses, and lichen species in areas that are depauperate or are dominated by a few species.

Structural Complexity– Priority will be given to potential upland planting sites where vertical and/or horizontal forest structure is relatively homogeneous. Introducing understory plants into forested areas emerging from the competitive exclusion stage, which are typically depauperate of understory vegetation, for instance, will improve canopy layering. Stand age and structural characteristics will also be examined when designing planting projects to account for individual species' preferences for light conditions, canopy closure, and overstory tree size. Mistletoe inoculation will be considered for forests that have little to no mistletoe within their boundaries or nearby, have not yet developed large thick branches or other broom-like features, contain appropriate host species, and support sun-exposed foliage.

Specific Wildlife Benefit – Upland planting could be used to benefit certain wildlife species by introducing habitat elements not currently found in certain areas (e.g., berry-producing shrubs could be planted to serve as a food source for willow flycatchers (*Empidonax traillii*)). Priority will be given to potential upland planting sites where planting could produce a specific wildlife benefit.

Road Access – Roads that are scheduled for decommissioning under the CRW-HCP will provide access to potential upland planting sites only until they are decommissioned. Therefore, potential planting sites that are accessible by roads scheduled to be decommissioned will have priority over those sites where roads will continue to provide access.

Likelihood of Re-entry – Priority will be given to potential upland planting sites where the initial planting effort will likely achieve planting goals. Potential sites where the likelihood of replanting is high, based on the failure of the initial planting effort, will have lower priority. Similarly, priority will be given to potential upland restoration planting sites in which no additional thinning entries are foreseen.

Monitoring Efficiency – Priority will be given to potential upland planting sites that provide for efficient effectiveness monitoring where monitoring is a project objective.

Affordability – Priority will be given to the potential restoration thinning sites that provide the greatest ecological benefit for the restoration cost.

3.3 Landscape-Level Prioritization Criteria

Proximity from Late-successional Habitat – Priority will be given to sites that are distant from existing mature and late-successional forest habitat where dispersal of plants associated with old-growth forests may be limited. Restoration planting will seek to compensate for low dispersal rates, lack of dispersal routes, missing seed sources, or insufficient passage of time.

Sub-Basin Planning – Priority will be given to potential upland planting sites that are located within watershed sub-basins where restoration activity is a priority.

Upper/Lower CRMW Connectivity – Priority will be given to potential upland planting sites that improve late-successional forest habitat connectivity between the upper and lower portions of the CRMW.

Proximity to other Upland Planting Sites – Priority will be given to potential upland planting sites that are in close proximity to one another.

Temporal Considerations – Priority will be given to potential upland planting sites that will most benefit late-successional forest habitat by the end of the CRW-HCP planning horizon (2051).

Coordination with other Restoration Projects – Priority will be given to potential upland planting sites that are in close proximity to or conducted in conjunction with other restoration efforts (e.g., ecological thinning, riparian restoration, road decommissioning).

Appendix D. Review of the datasets currently on-hand and under development at the Watershed Management Division that are most relevant to upland forest restoration.

On-hand datasets:

Mason, Bruce, and Girard Forest Inventory, 1992-94, 1997 – Consultant Mason, Bruce, and Girard (MBG) conducted an inventory of approximately 24,175 acres of forest in the CRMW that was intended to sample the forest classes developed in the TBS layer. The inventory consisted of 2,490 field plots placed along a series of regularly spaced transects. Data collection protocols consisted of variable radius plots for tree data, 0.05-acre fixed plots for snag, stump, shrub, and herb measurements, and 66.7 foot transects to measure downed wood. The inventory provides good quality data giving an accurate snapshot of forest condition in 1992-94. The shrub, herb, snag, stump, and downed wood data are especially valuable, because these types of data have rarely been collected in the CRMW.

Timber Stand (TBS) GIS Layer, 1994 – The TBS layer consists of a classification of 1988 LANDSAT Thematic Mapper (TM) satellite image data based on field data taken on U.S. Forest Service ownership outside the CRMW. Developed by Pacific Meridian Resources, Inc. (PMR), 108 possible forest classes were identified based on three cover attributes: tree crown closure (three classes), tree diameter size class (four classes), and dominant tree species (nine classes). Since PMR used proprietary methods to develop the data, no documentation of the classification techniques or accuracy was provided. A third party evaluation of the TBS layer by a forest modeling consultant (Jim Arney) found that the three cover attributes were consistent with aerial photo interpretation, but that the polygon delineation produced results inconsistent with aerial photo interpretation. WMD staff also found that the results of the classification were not consistent with field observations. Although we have low confidence in TBS polygons because of the within and between polygon variation, it is currently the only CRMW-wide dataset available for tree attributes. A re-evaluation of the original 30-meter resolution LANDSAT raster data is possible, however, that effort would likely yield less useful information than more current image data with greater resolution (see Section 6.3).

Measured tree attributes from the MBG inventory (e.g., species, density, diameter, basal area, dominant height) were later ascribed to all polygons in the TBS layer, either directly from coincident location of polygon and plot or indirectly by correlation between TBS class and plot attribute. These expanded data are of questionable accuracy because of the lack of confidence of the TBS layer (described above), and the potential inconsistency between the field locations of the plots and those digitized in the GIS. Again, although we have low confidence in the expansion of forest attribute data to the TBS layer, it is currently the only CRMW-wide dataset on-hand. There is currently an effort to assess the accuracy of the MBG plot locations, and the expansion of attribute data to areas not sampled in the field using the TBS dataset or other image data (see Section 6.3).

Old-Growth Forest Map, 1994 – Old-growth forest in the CRMW, as defined as greater than 190 years of age or having never subject to timber harvest, were delineated using the TBS layer supplemented with 1991 aerial photo interpretation. The defined boundaries were visually later inspected in a nonsystematic fashion using the 1998 orthophotography and 2000 IKONOS multi-spectral imagery. While most areas identified appear to include old-growth forest, the actual extent of old-growth forest is subject to the problems inherent with TBS layer (see above).

Walker Forest Inventory, 1974 – The Walker forest inventory measured forest attributes in 999 0.1-acre plots over 44,654 acres of second-growth forest in the CRMW. The area sampled did not include young or old-growth forest on the City of Seattle's ownership, or land owned at the time by the U.S. Forest Service. All trees greater than six inches dbh were measured in each plot for dbh and species, and five trees were cored for age. The plots were placed into polygons developed from aerial photo interpretation. This dataset is considered to be the most accurate estimate of tree age for the CRMW.

CRW-HCP Tree Age Map, 1998 – This map utilized the best available information on tree age, including the Walker forest inventory data, old-growth delineation, and recent clearcut harvest data, to classify TBS layer polygons according to age. It provides the best available estimate of tree age throughout the CRMW, but is subject to the problems inherent with TBS layer (see above).

Historical Forest Thinning Map, 1967-1982 – The historical thinning and planned thinning data layer is a map intended to capture the extent and timing of planned commercial thinnings of upland forest in the CRMW between 1967 and 1982. A digital version of these historical maps was created to preserve the information. These maps have not been geometrically registered to the existing standard of the 1998 orthophotography coverage. There is no documentation that the areas mapped as planned thinning were field checked to verify that the thinning actually occurred. The historical data may be helpful in delineating areas that do not need thinning.

Historical Forest Harvest Map, 1911-1981 – This map documents the location and timing of clearcut timber harvest that occurred in the CRMW from 1911 to 1981. A digital version of these historical maps was created to preserve and allow greater access to the information. It provides a useful tool when planning upland forest restoration projects, corroborating the age data obtained in the Walker forest inventory. It also provides a landscape level view of past forest management, which is essential in basin or landscape scale planning.

Restoration Thinning Map, 1995-2003 – The recent restoration thinning layer documents all recent thinning of young forests, generally called pre-commercial thinning (PCT) prior to the CRW-HCP. It will be used to document the extent of the restoration thinning program, and potentially will be used to identify potential ecological thinning project sites in the future.

Road and Stream GIS Layers – Stream and road data were obtained from the WDNR. There is no documentation of the methods used to develop these layers. Knowing the location of historical roads could provide valuable information about potential within-site access when planning restoration projects, as well as a predictive tool about the types of plants that are likely to occur there. Though these layers are currently the best available, in some cases streams or roads do not align with the 1998 orthophotography, or are incorrectly placed or missing.

Slope and Aspect GIS Layers – Slope and aspect are calculated from Digital Elevation Model (DEM) data obtained from WDNR. These layers are generally considered to be accurate, especially for steep slopes, though some artifacts may be present, especially at lower slopes.

Soil Survey and Site Class Maps – A soil survey was completed for eastern King County in 1980 by the Soil Conservation Service (SCS, 1986). Data from this survey, which are the best available for soil distribution in the CRMW, was developed into site class map based on Douglas-fir growth potential by WDNR. There are some discrepancies between the soil survey and the site class boundaries, but in general the site class layer is considered to be accurate at a coarse scale.

Historical Lower CRMW Permanent Sample Plots – Permanent sample plots (PSPs) were established at various times in 21 forested areas in the lower (western) CRMW. Nineteen of the plots were established in the 1940s and 50s, with the remaining two established in the late 1970s. Sampling protocol differed throughout the plots, with various plot sizes (from 0.2 to 1.0 ac) and shapes (single circle, multiple circles, and rectangle). Most measurements concentrated on trees. Plots were remeasured various numbers of times (1-9) and at various intervals (from 1-19 years), most recently in 1986 for 18 of the plots. Methods used at the same plot in different years may have varied. Plots were in forest areas of various ages. Some plots were thinned, others fertilized, and others clearcut harvested. Documentation of methods and variables measured at each plot is available in hard copy only, although conversion to electronic format is underway. Analysis of the methods and data should provide valuable local information on forest development and can be used as the basis for forest growth and habitat modeling. We plan to leverage these long-term datasets with future monitoring plots.

Datasets under development:

2001 MASTER Data – Remotely sensed data was obtained for the entire CRMW in August of 2001 from an airborne version of the Moderate Resolution Imaging Spectrometer – Advanced Spaceborne Thermal Emission and Reflection Radiometer (MASTER) sensor, and is currently being developed by WMD staff. Data produced by the MASTER sensor is in 50 spectral bands with 5-meter resolution. It is anticipated that classification of this data will eventually provide landscape maps of tree species or species group, canopy closure, tree density, and tree diameter. Products from this dataset are estimated to be available beginning in the spring of 2004, pending field validation using permanent sample plots (PSPs) (see below) and other field data (e.g., MBG Forest Inventory Data).

2003 LIDAR Data – Remotely sensed data was obtained for the entire CRMW from an airborne Light Detection and Ranging (LIDAR) sensor. LIDAR data is available via King County through a data sharing agreement in the spring of 2004, when the contractor (Spectrum Mapping, LLC) completes post-processing. It is anticipated that classification of this data will eventually provide maps of elevation, slope, roads, and streams over portions or all of the CRMW. LIDAR may also provide an assessment of understory vegetation, and a more accurate assessment of tree density, tree diameter, and tree canopy closure and layering.

Permanent Sample Plots, 2003-2004 – Permanent sample plots (PSPs) are currently being installed throughout the various forest types in the CRMW. Tree data from 0.2 and 0.4-acre fixed radius plots include species, diameter, height, canopy structure, and age. Understory vegetation data is being collected in a series of plots and transects including information on tree seedling/sapling, shrubs, herbs, and downed wood. Phase one of the data acquisition was completed in autumn of 2003, with 19 plots in old-growth forests throughout the CRMW. Phase two has been contracted as series of 80 plots in all other forest ages. Tree data will be available by the summer of 2004, while understory data will be available in the fall of 2004. Additional plots may be warranted pending the statistical requirements of utilizing the data.

It is anticipated that these data will be used to drive and verify the classification of the MASTER and LIDAR data, and serve as a tool for long-term ecological monitoring of forest succession. At a minimum, tree density, diameter, species, and canopy closure must be measured in the field in a variety of forest types and conditions. The plots were located by placing a randomized grid of 310 points over the CRMW, and finding those points in the field. Plot locations are being permanently marked in the field, which is essential for long-term ecological monitoring (Munro et al. 2003, Nickelson et al. 2003). The primary disadvantage to PSPs is the potential expense of installation and more extensive data collection required (including an adequate number of trees to monitor forest processes through time). If the installation expense is averaged over the length of the monitoring period (>50 years) and the clear benefits of repeated sampling are considered, however, the cost is reasonable (Munro et al. 2003).

Forest Inventory, 2001-to be determined – Forest inventories have and will take place in forested areas that have been selected as possible thinning sites following the coarse-filter site selection and landscape-level prioritization. Inventory data will generally consist of geographically-referenced detailed estimates of tree diameters per species, tree density, tree growth rates, tree height, and live tree crown. Forest inventories utilize typical timber cruise methods in fixed or various radius plots. Typically the plots are not permanently marked, and a limited number of trees are measured (usually 5-8). An augmented forest inventory could include shrub, herb, and downed wood measurements. This type of data would be useful as a fine-filter for site selection. To minimize costs, we propose that these data be collected on a subsample of the total acres available for ecological thinning. These data could be used to describe ecological thinning sites and develop prescriptions for restoration.

The primary forest attributes that drive the coarse-filter site selection of upland forest restoration sites are tree density, tree diameter, and canopy closure. Ground sampling plots alone would provide data for these attributes at point locations and would likely require prohibitively expensive numbers of plots to capture the range of variation present in the CRMW. Extrapolation from a fixed number of ground plots to the remaining areas using image data would provide a statistically valid method of assessment of forest attributes on a landscape scale. We support the use of image data to provide landscape coverage of forest attributes over the entire CRMW.

We recommend that the most cost-effective method to develop forest attribute data across the CRMW would be using a combination of MASTER and LIDAR data, and focusing on areas already filtered by more general attributes such as tree age, slope, and elevation data. In addition to the primary forest attributes, LIDAR and MASTER data combined can provide estimates of horizontal structural diversity. Large-scale aerial photography could provide an alternative to MASTER and LIDAR data, although the required level of effort would be very high. Individual tree crowns would need to be discernable, a correlation between tree crown size and diameter would need to be established, and interpretation would be manual and open to bias, requiring a person with specialized knowledge and background in photogrametry.

Fine-filter site selection forest attributes such as canopy layering, understory development, snags, downed wood, and live crown ratio can only be obtained from field measurements (e.g., modified forest inventory). We recommend obtaining these data on the limited number of sites remaining after the coarse-filter site selection forest attributes are considered using the image data. For many sites, detailed field data may not be necessary and a walk-through assessment by staff with a qualitative description of these variables may suffice. This cursory assessment would involve minimal cost.

Appendix E. Methods for spatially modeling coarse-filter site selection criteria for identifying potential near-term ecological thinning projects.

A spatial model was created by the Upland Forest Restoration Interdisciplinary Team (UFRIDT) and other members of the Watershed Management Division (WMD) for applying the course-filter site selection criteria (see Section 5.2) to data currently on-hand (see Section 6.2) to identify potential near-term ecological thinning projects. This model resulted in a map of the Cedar River Municipal Watershed (CRMW) that shows second-growth forests in one of five site selection classes: high to low, with high areas having the forest characteristics that would most ecologically benefit from ecological thinning (see Section 3.0). This appendix outlines the methods used to create this model.

Step 1. Weight the pre-existing classes of landscape-level data for each coarse-filter site selection criteria (Table B1). The weighting was done subjectively based on informed professional opinion of forest characteristics that most benefit from thinning. Relative density (RD) was not included because it could not be calculated accurately enough from the available classified tree density and diameter data. Aspect was not included because, as stated in Section 5.2.1, it generally does not play a major role in determining an appropriate site for an ecological thinning project, especially in relatively flatter areas. Elevation was not included because the majority of forest over 4,500 feet is currently either too young (26 percent) or too old (68 percent) for ecological thinning, and the other 151 acres may benefit from ecological thinning based on fine-filter site selection criteria. (Note: None of the potential near-term ecological thinning project sites is over 4,500 feet in elevation.)

Table B1. Weighting of coarse-filter site selection criteria.

Dataset*	Source**	Class	Weight	Dataset*	Source**	Class	Weight
Tree Density	TBS, MBG	0-200/acre	0	Crown Closure	TBS	<10%	0
		200-300/acre	3			10-40%	0
		300-400/acre	7			41-70%	0
		400-1000/acre	10			>70%	4
		1000-3000/acre	7	Site Class	Soil Survey	I	0
		>3000/acre	3			II	0
Tree Diameter	TBS, MBG	0-5"	0			III	2
		5-9"	8			IV	2
		9-21"	7			V	0
		>21"	0	Slope	DEM	0-35%	3
Relative Density	NA					35-70%	2
Stand Age	Walker	0-35 yrs	0			>70%	1
		35-50 yrs	4	Aspect	DEM	N	NA
		50-80 yrs	6			S	NA
		80-100 yrs	2			E	NA
		>100 yrs	0			W	NA
Elevation	DEM	<4,500'	NA				
		>4,500'	NA				

*see Section 5.2 NA = not available

**see Section 6.2

Step 2. Apply class weightings mathematically to GIS data. This requires the conversion of all spatial data to a common grid cell size (in this case 33.842 feet or 10 meters), reclassification of criteria classes to designated weights (Table B1), and the generation of a total weight for each cell through summing each criterion weight for that cell.

Step 3. The resulting map of total weights from Step 2 displayed a very high degree of spatial variability which limited its application to less than landscape-level planning. A smoothing algorithm was applied to the total weights data to generate a map where each grid cell obtains the value of the average of all cells within a 14-cell radius (e.g., the nearest 620 cells, 475-foot circle, 16.3-acre circle).

Step 4. The smoothed map from Step 3 had values from 3 to 33 and was simplified by evenly reclassifying the data to 5 classes of high, medium-high, medium, medium-low, and low. This map is displayed in Figure 1.

Appendix F. Outlines of individual project management plans.

Below are examples of outlines of individual project management plans. These outlines are made as suggestions and are expected to evolve over time as specific plans are written and implemented.

1) An example of an ecological thinning plan outline from the table of contents of the 700 Road Forest Restoration Management Plan:

6.0 SPECIFIC THINNING PRESCRIPTIONS

6.1 Data and Scenarios Considered
6.2 Thinning Prescriptions
6.3 Future Silvicultural Treatments

7.0 LOGGING/ ENGINEERING SYSTEM

8.0 RISKS, BENEFITS, AND COSTS

8.1 Risks
8.2 Benefits
8.3 Costs

9.0 MONITORING

9.1 Compliance Monitoring
9.2 Effectiveness Monitoring
9.3 Validation Monitoring

10.0 IMPLEMENTATION AND DOCUMENTATION

10.1 Seattle City Council Ordinance
10.2 Contracts
10.3 Project Completion

11.0 LITERATURE CITED

2) An example of a restoration thinning plan outline from the table of contents of the 2003 Restoration Thinning Management Plan:

EXECUTIVE SUMMARY

1.0 INTRODUCTION

1.1 Background
1.2 Authority
1.3 HCP Upland Forest Goals
1.4 HCP Upland Forest Management Activities
1.5 Site Selection
1.6 Scoping

2.0 ECOLOGICAL PROCESSES

2.1 Forest Development
2.2 Disturbance Effects
2.3 Late-successional Forest Conditions

3.0 ECOLOGICAL OBJECTIVES

3.1 Objective 1: Maintain or Increase Growth Rate of Trees
3.2 Objective 2: Increase Plant Species Diversity
3.3 Objective 3: Accelerate Structural Development